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FRACTIONS OF ARSENIC, COPPER, AND CHROMIUM DURING AEROBIC COMPOSTING PROCESS OF CHICKEN MANURE AND CCA-TREATED WOOD

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Environmental Management
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Thesis Title	FRACTIONS OF ARSENIC, COPPER AND CHROMIUM DURING AEROBIC COMPOSTING PROCESS OF CHICKEN MANURE AND CCA-TREATED WOOD
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Field of Study	Environmental Management
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ณีระย้า รัตนศาสตร์ชาญ: การเปลี่ยนแปลงของอาร์เซนิค ทองแดง และโครเมียม ในระหว่างกระบวนการหมักมูลไก่กับไม้อัดน้ำยาซีซีเอ (FRACTIONS OF ARSENIC, COPPER AND CHROMIUM DURING AEROBIC COMPOSTING PROCESS OF CHICKEN MANURE AND CCA-TREATED WOOD) อ. ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. สมใจ กาญจนวงศ์, 192 หน้า.

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาการเปลี่ยนแปลงรูปแบบของอาร์เซนิค ทองแดงและโครเมียม ในระหว่างกระบวนการหมักมูลไก่กับขี้กบจากไม้อัดน้ำยาซีซีเอที่มีปริมาณของไม้อัดน้ำยาซีซีเอต่างกัน 4 สัดส่วนในช่วงร้อยละ 0, 33, 66 และ 100 โดยน้ำหนักแห้ง โดยใช้กล่องหมักที่มีการเติมอากาศแบบแพสซีพขนาด 1 ลูกบาศก์เมตร ระยะเวลาในการหมัก 140 วัน ในระหว่างดำเนินกระบวนการหมัก ได้ทำการวัดอุณหภูมิในถังหมักแต่ละถัง วันละ 1 ครั้ง ทำการวิเคราะห์หาพีเอช การนำไฟฟ้า คาร์บอน ไนโตรเจน อัตราส่วนคาร์บอนต่อไนโตรเจน ค่าร้อยละของแข็งระเหยได้ ดรรชนีการงอกของเมล็ดผักกวางตุ้ง และการเปลี่ยนแปลงรูปแบบของโลหะหนัก โดยใช้วิธีการสกัดโลหะหนักแบบ Sequential extraction ทำการเก็บตัวอย่างสัปดาห์ละ 1 ครั้ง หลังจากนั้น นำปุ๋ยหมักที่ได้ที่แล้วจากแต่ละกล่องหมักมาผสมกับดิน เพื่อทำการปลูกผักกวางตุ้ง เป็นเวลา 45 วัน ทำการเก็บตัวอย่างดิน และ ผักกวางตุ้งทุก 15 วัน สังเกตการเจริญเติบโตของผักกวางตุ้ง และทำการศึกษาการเปลี่ยนแปลงรูปแบบของโลหะหนักในดินและพืชที่ได้

ผลการศึกษาพบว่าจุลินทรีย์สามารถย่อยสลายสารอินทรีย์ในวัสดุหมักได้แม้ว่าจะมีขี้กบจากไม้อัดน้ำยาซีซีเอในวัสดุหมักที่สัดส่วนที่สูง การเปลี่ยนแปลงของอุณหภูมิ พีเอช คาร์บอน ไนโตรเจน ค่าร้อยละของแข็งระเหยและอัตราส่วนคาร์บอนต่อไนโตรเจนของวัสดุหมัก มีค่าลดลงอย่างต่อเนื่องและคงที่ในช่วงเวลาการหมักในช่วง 95-140 วัน โดยไม่พบความแตกต่างของค่าเฉลี่ยของพารามิเตอร์ดังกล่าวของปุ๋ยหมักจากทั้ง 4 กองอย่างมีนัยสำคัญ ค่าดรรชนีการงอกของเมล็ดผักกวางตุ้งมีค่าเพิ่มขึ้นเมื่อระยะเวลาการหมักเพิ่มขึ้น และมีค่าแปรผกผันตามสัดส่วนของไม้อัดน้ำยาซีซีเอที่สูง ความเข้มข้นของอาร์เซนิค ทองแดงและโครเมียมมีค่าเพิ่มขึ้นเมื่อระยะเวลาการหมักเพิ่มขึ้น โดยสัดส่วนของอาร์เซนิคหลังการหมักมีแนวโน้มเปลี่ยนไปอยู่ในรูปไอออนอิสระและรูปดูดซับมากขึ้น ส่วนทองแดงและโครเมียมเปลี่ยนไปอยู่ในรูปที่คงตัวมากขึ้น ผลการศึกษาการเปลี่ยนแปลงของโลหะหนักในดินที่ผสมกับปุ๋ยหมักพบว่าทองแดงและโครเมียมส่วนใหญ่อยู่ในรูปที่คงตัว ส่วนอาร์เซนิคจะพบมากในรูปของโลหะหนักที่ละลายน้ำได้ เมื่อทำการศึกษารูปแบบของโลหะหนักในพืชพบว่า ทองแดงและโครเมียม มีการสะสมมากที่ราก แต่อาร์เซนิคส่วนใหญ่จะสะสมอยู่ในลำต้นและใบ และพืชสามารถเจริญเติบโตได้ในดินที่ผสมปุ๋ยหมักที่มีส่วนผสมที่เป็นขี้กบจากไม้อัดซีซีเอที่สัดส่วนร้อยละ 0 และ 33

จากผลการศึกษาในครั้งนี้สามารถสรุปได้ว่า สัดส่วนของขี้กบจากไม้อัดน้ำยาซีซีเอในวัสดุหมักไม่มีผลต่อความสามารถในการย่อยสลายสารอินทรีย์ของจุลินทรีย์ในกระบวนการหมัก แต่การผสมขี้กบไม้อัดน้ำยาซีซีเอในวัสดุหมักในสัดส่วนที่สูงมีผลต่อความเป็นพิษต่อพืชเมื่อนำปุ๋ยที่ได้ไปใช้ สัดส่วนสูงสุดของขี้กบจากไม้อัดน้ำยาซีซีเอที่ใช้เป็นวัสดุหมักร่วมคือที่ค่าร้อยละ 33 ของส่วนผสมที่เป็นขี้กบจากไม้ทั้งหมด โดยปุ๋ยหมักที่ได้ เมื่อนำไปผสมดินเพื่อปลูกผักกวางตุ้ง พบว่าไม่เกิดความเป็นพิษต่อการเจริญเติบโตของผักกวางตุ้ง

สาขาวิชา การจัดการสิ่งแวดล้อม ลายมือชื่อนิสิต

ปีการศึกษา 2552 ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก

5187530120: MAJOR ENVIRONMENTAL MANAGEMENT
KEYWORDS: AEROBIC COMPOSTING/ ARSENIC/ CCA-TREATED WOOD/ CHICKEN MANURE/ CHROMIUM/ COPPER/ SEQUENTIAL EXTRACTION

NEERAYA RATTANASATCHAN: FRACTIONS OF ARSENIC, COPPER, AND CHROMIUM DURING AEROBIC COMPOSTING PROCESS OF CHICKEN MANURE AND CCA-TREATED WOOD. THESIS ADVISOR: ASSOC. PROF. SOMJAI KARNCHANAWONG, M.Sc., 192 pp.

This study was conducted to evaluate the fractions of heavy metals during aerobic composting process of 4 piles, each comprising chicken manure and 4 different proportions of CCA-treated wood shavings (0%, 33%, 66%, and 100% dry weight of CCA-treated wood in the wood material added in the compost mix). Each pile was composted in a 1-m^3 wood box with passive aeration. The temperature at the central portion of each pile was measured daily while the compost characteristics and germination index using *Brassica campertris var. chinensis* were monitored on samples collected weekly. The changes in heavy metals based on Cu, Cr and As fractionations during aerobic composting process were determined by a sequential extraction procedure. After the maturity of compost reached, the mature compost were amended with soil in 1:2 ratios for planting the *Brassica campertris var. chinensis* for 45 days. The characterizations of plant and variation of heavy metals in soil and plant during 45 days of planting were investigated.

The results showed that the microorganisms could degrade the organic matter in all compost piles even for the highest proportion of CCA-treated wood in the compost mixture. During the composting process, the variation patterns of temperature, pH, organic carbon, total nitrogen, total volatile solid and C/N ratio of four piles gradually decreased and were stable during the composting period of 95 to 140 days. The average values of those parameters of four piles were not significantly different. During composting, the pile with high CCA-treated wood portions had significantly lower values of GI. The concentrations of Cu, Cr and As increased with time of composting. The results of the sequential extraction showed that during the composting process, As was mainly redistributed into the mobile fraction, whereas Cu and Cr had an affinity for the stable fraction. After amending the compost with soil, the Cr and Cu were present in the less available forms for soil organisms and plants whereas As was mainly in the mobile phase, in which considered as the bioavailable element. These three metals found in plants were associated with water soluble form. The accumulations of Cu and Cr mostly were found in the root part whereas As mostly was found in the above-ground parts. The plant could grow without any effect in the soil amended compost containing 0 and 33 % of CCA-treated wood.

It could be concluded that the presence of CCA treated wood in the compost mix did not have any influence on the decomposition of organic matter in the composting process. However, the high proportion of CCA-treated wood in the compost mix could have an effect on the phytotoxicity. The maximum proportion of CCA-treated wood shaving used in the compost mixture without phytotoxicity effect was 33% of total wood shaving weight.

Field of Study : Environmental Management Student's Signature : Neeraya R.
Academic Year : 2009 Advisor's Signature: Somjai Ka

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LIST OF ABBREVIATIONS

AAS	Atomic absorption spectrophotometer
AOAC	Association of Official Analytical Chemists
As	Arsenic
As(III)	Arsenite
As(V)	Arsenate
As_2O_5	Arsenic pentaoxide
AWPA	American Wood Preservative Association
C	Carbon
C/N	Carbon per nitrogen
C&D	Construction and demolition
CCA	Chromated copper arsenate
Cr	Chromiun
Cr(III)	Trivalent chromium
Cr(VI)	Hexavalent chromium
Cu	Copper
CuO	Cuprix oxide
°C	Degree Celsius
EPA	Environmental Protection Agency
GI	Germination Index
mg/kg	Milligram per Kilogram
ppb	Part per billion
ppm	Part per million
SEA	Sequential Extraction Analysis
TAS	Thai Agriculture Standard
TN	Total nitrogen
TOC	Total Organic Carbon
TVS	Total volatile solid
USEPA	United States Environmental Protection Agency

CHAPTER I

INTRODUCTION

1.1 Introduction:

Chromated copper arsenate (CCA) is the most common preservative found in treated wood worldwide as it can enhance the service life of wood by 20 to 40 years. CCA-treated wood has been applied to wood used in a wide range of applications. Utility poles, wooden playground equipment, foundation wood, garden projects, and marine piles are example of their wide use. The CCA treating solution usually consists of a mixture of hexavalent chromium (CrO_3), divalent copper (CuO), and pentavalent arsenic oxides (As_2O_5). The copper (Cu) in treated timber serves as the fungicide, whereas the arsenic (As) protects the wood against attacks by insects. The chromium (Cr) promotes the fixation of the copper and arsenic in the wood through the formation of soluble metal complexes, such as $CuCrO_4$ and $CrAsO_4$ (Pizzi, 1982). The disposal of decommissioned CCA-treated wood is of increasing concern because of the high concentrations of toxic contaminants present in the treated wood and the large volumes of decommissioned CCA-treated wood being generated. With an average service life of 20 to 25 years, increased volumes of decommissioned wood treated with inorganic preservatives are expected in the coming decades. In the USA and Canada, 3 to 4 million m^3 of CCA wood are currently decommissioned annually, and this amount is expected to increase to 16 million m^3 by 2020 (Cooper, 2003). The presence of toxic components makes CCA treated timber harmful to the environment at the end of its service life. The leaching of chemicals from CCA treated wood can deteriorate the soil quality, groundwater quality, and/or surface water quality. CCA is highly toxic to human health and the environment as the arsenic and chromium are known as human carcinogens and have been linked to nervous system damage and birth defects in addition copper has a high aquatic toxicity (Becker *et al*., 2001). In view of the increased volume of CCA treated wood waste and their potential hazards, alternative waste management practices are needed to address current and future disposal issues associated with discarded CCA-treated wood.

The composting of the wood waste may be an alternative solution for reducing the weight and toxicity of the waste (Borazjani *et al*., 1997, 2000; Vidali, 2001). Composting is an aerobic biological process, in which biodegradable organic matter is converted into an innocuous stable humus material by the actions of microorganisms. Amending high carbon containing wood waste with a high nitrogen feedstock may enhance the composting process. Researchers have conducted a study on the co-composting of wood residues and feedlot manure by using poultry manure, cow manure, horse manure, gin trash and inorganic fertilizers as amendments (Borazjani *et al*., 2000). The best results in terms of reduction in toxicity, weight loss, and color change were obtained with poultry manure amended treatments (Borazjani *et al*., 2000). Barker and Bryson (2002) have revealed that metallic pollutants can be converted into less bioavailable organic species. The overall conclusion drawn from the study was that the composting process may be a promising way to degrade or bind pollutants to innocuous compounds and, therefore has the potential to remediate polluted materials. The quantity, the mobility and the bioavailability of heavy metals are considered to be important for predicting the release of the heavy metals into soil and their subsequent absorption by plants. An approach commonly used for studying metal partitioning and mobility in composting makes use of sequential extraction procedures. These procedures do not provide a direct characterization of metal speciation, but rather an indication of a metal binding form or its partitioning. The sequential extraction procedures are able to isolate the fractions of heavy metals in terms of metal bioavailability (Song and Greenway, 2004).

A plant's uptake of trace elements is generally the first step of the elements entry into the agricultural food chain. Plant uptake is dependent on (1) the movement of elements from the soil to the plant root, (2) the elements crossing the membrane of the epidermal cells of the root, (3) the transport of elements from the epidermal cells to the xylem, in which a solution of elements is transported from the roots to shoots, and (4) the possible mobilization of the elements, from the leaves to storage tissues used as food (seeds, tubers, and fruit), in the phloem transport system. After plant uptake, metals are available to herbivores and humans both directly and indirectly through the food chain. Therefore, it is essential to study heavy metals from the compost. Phytotoxicity technique is the alternative, and may occur with mature composts due to substances which are not removed in the composting process (e.g. heavy metal, persistent herbicides).

1.2 Objectives of the study:

The main aim of this study is to investigate the fate of Cu, Cr, and As fractionation throughout the aerobic composting process of CCA treated wood and chicken manure.

The specific objectives are:

1. To determine the fate of arsenic, chromium and copper from the aerobic composting process by using the sequential extraction procedure.
2. To investigate the metals uptake by plants using soil amended with co-composting of CCA-treated wood and chicken manure.

1.3 Hypotheses:

1. The aerobic composting of CCA treated wood with chicken manure can be applied to lessen the bioavailability of arsenic, copper, and chromium in CCA treated wood before its disposal.
2. The efficiency of organic matter decomposition from the aerobic composting process depends on the composting time and portions of CCA treated wood and chicken manure.
3. The proportion of Cu, Cr and As during compost would be high in stable phase after the composting process finished, and cannot be mobilized to soil amended.

1.4 Scope of the study:

The experiment is divided into two phases as follows:

Phase 1: The aerobic composting process.

The aerobic composting pile in this experiment was conducted in a laboratory scale. Composting materials consisted of wood shaving from new untreated wood, wood shaving from CCA treated wood waste, and chicken manure. In addition, the household organic waste compost was seeded in order to accelerate the biodegradation process. The initial C/N of the compost mix was controlled to be around 25/1. Four piles of wood shaving with different portions of CCA treated wood were set up to conduct the experiment. Sequential extraction analysis (SEA) was used to investigate the geochemical partitioning of arsenic, copper and chromium during the aerobic composting process. The concentration of arsenic, copper and chromium from each of the SEA fractions were analyzed by Atomic Absorption Spectroscopy (AAS).

Phase 2: The metal plant uptake tests.

The metal plant uptake test was proposed using a pot test, growing *Brassica campertris var. chinensis* seeds. The mature composts from phase 1 were mixed with soils in which the plants were grown and also the pure CCA treated wood without soil mixing. Six groups of pot tests were set up to conducted the experiment. Groups 1 to 5 were set up with different portions of soil and the mature compost from phase 1. Group 6 was set up with pure CCA treated wood. The plants were raised for 45 days in pots. The sampling of plants and soil were conducted every 15 days. The plant growth was determined by measuring the lengths and weights of the fresh roots, trunks and leafs. Sequential extraction analysis (SEA) was used to investigate the geochemical partitioning of arsenic, copper and chromium in the pure soil, the soil mixed with compost and the parts of the uptake plant (the root, leaf, and trunk) during the growth process. The concentrations of arsenic, copper and chromium from each SEA fraction were analyzed by using Atomic Absorption Spectroscopy (AAS).

CHAPTER II

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 General information on Chromated Copper Arsenate (CCA)

When left untreated, wood in many outdoor applications becomes subject to degradation by a variety of natural causes. Wood can be protected from the attack of decay fungi, harmful insects, or marine borers by applying a chemical preservation method such as CCA to prolong its life. CCA is used for the control and prevention of damage to timber and timber structures by insects, wood rot, wood fungus and general timber decay. CCA is generally used on wood intended for outdoor uses, such as telephone poles, decking, fencing, in landscaping, and in building structures. CCA treated wood is also commonly used in playgrounds, children’s cubbyhole, public picnic tables, garden edgings, handrails, boat bulkheads, dock pilings and vineyard stakes. CCA-treated timber can often be identified when it is new by its green tinge but this fades with time. Wood preservatives can be divided into two general classes: (1) oil-borne preservatives and (2) waterborne preservatives such as chromated copper arsenate (CCA). Chromated copper arsenate treated wood contains copper, which serves as a fungicide; arsenic, which serves as an insecticide; and chromium, which is used to “fix” the copper and arsenic onto the wood. There are three types of CCA-treated wood: Type A, Type B, and Type C. The most common type is CCA-Type C (AWPA, 1996). The compositions of CCA-Type A, B, and C are provided in Table 2.1. The amount of CCA utilized to treat the wood or “the retention level’ depends upon the particular application of the wood product. Typical retention levels utilized by industry are 4.00 kg/m^3, 6.40 kg/m^3, 9.61 kg/m^3, 12.81 kg/m^3, and 40.04 kg/m^3 (0.25 pcf, 0.40 pcf, 0.60 pcf, 0.8 pcf, and 2.50 pcf, pcf = pounds of chemical per cubic foot of wood). Low retention values (4.00 kg/m^3) are permissible for plywood, lumber, and timbers if the wood is used for above ground applications. Higher retention values are required for load bearing wood components such as pilings, structural poles, and columns. The highest retention levels (12.81 kg/m^3, and 40.04

kg/m^3) are required for wood components that are used for foundations or saltwater applications (AWPA, 1996). The retention requirements for CCA-treated wood are shown in Table 2.2.

Table 2.1 Compositions of CCA-Types A, B, and C (AWPA, 1996)

	Chromium		**Copper**		**Arsenic**	
	CrO3 (%)	Cr(%)	CuO (%)	Cu (%)	As_2O_5 (%)	As (%)
CCA-Type A	65.50	34.06	18.10	11.50	16.40	24.70
CCA-Type B	35.30	18.36	19.60	12.45	45.10	33.78
CCA-Type C	16.40	24.70	18.50	11.75	34.00	25.47

Table 2.2 Retention requirements for CCA-Treated Wood (AWPA, 1996)

Application	**Retention Value (kg/m^3)**
Above ground: lumber, timbers, and plywood	4.00
Ground/freshwater contact: lumber, timbers, plywood	6.40
Salt water splash, wood foundations: lumber, timbers, and plywood structural poles	9.61
Foundation/Freshwater: pilings and columns	12.81
Salt water immersion: pilings and columns	40.04

2.1.1 General information on treating processes

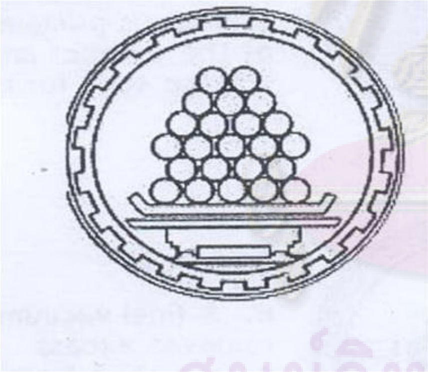
There are three broad classes of preservatives used for the pressure treatment of wood products:

- **Waterborne** preservatives serve a wide variety of uses, including residential, commercial, marine, agricultural, recreational, and industrial applications.
- **Oil borne** preservatives are used primarily for applications such as utility poles, piling, posts, glulam beams, and timbers.
- **Creosote** preservatives, including creosote/coal tar mixtures, protect railroad ties, marine pilings, and utility poles.

For most residential, commercial, and marine building applications, waterborne preservatives are most often specified. Waterborne treatments are clean in appearance, odorless and paintable, and they are EPA-registered for both interior and exterior use without a sealer.

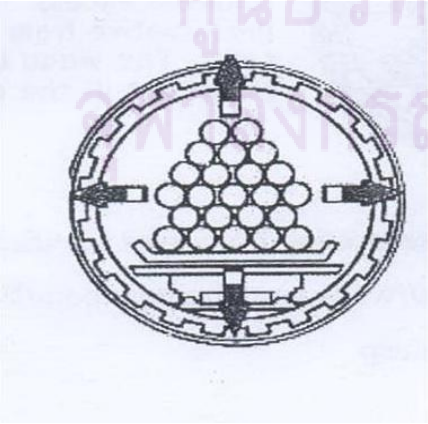
- **CCA pressure treating process**

Pressure-treated wood is the product of a carefully monitored and controlled process. Within a closed cylinder, preservatives are forced into the wood cells under pressure. The fixation process bonds the preservative within the wood fiber. This begins during the treating cycle, but continues after removal from the cylinder. The time needed to complete fixation can range from several hours to several days depending on the type of preservative, and weather conditions. CCA pressure treating processes are described in Figure 2.1:



Step 1

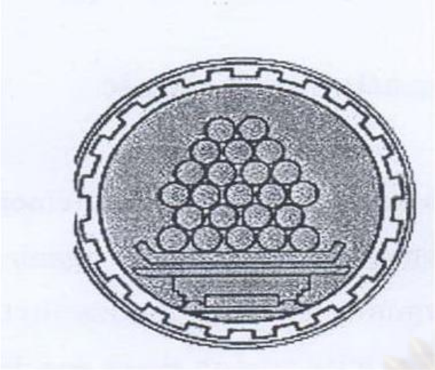
Dry lumber-or timbers, plywood, or poles-is loaded into the treating cylinder.



Step 2

An intial vacuum pulls air from the cylinder and from the wood cells, making space for the preservative.

Figure 2.1 CCA pressure treating processes

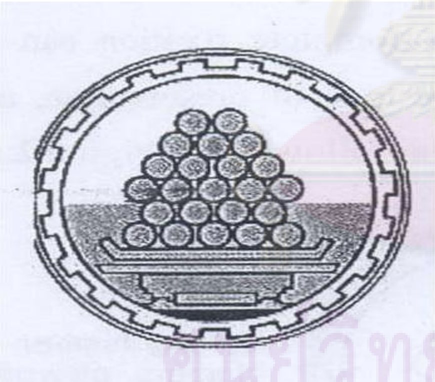


Step 3

A diluted solution of preservative is introduced into the cylinder.

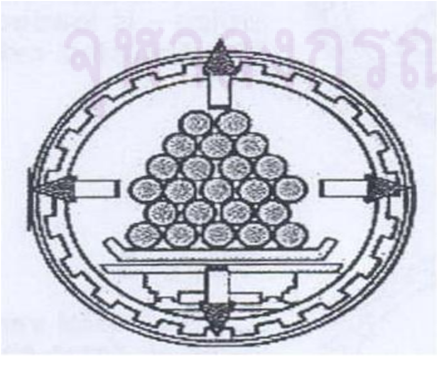
Step 4

Pressure pumps then force the liquid into the wood until adequate penetration is assured.



Step 5

At the end of the pressure period, remaining preservative solution is pumped out of the cylinder and into a storage tank for later reuse



Step 6

A final vacuum removes excess preservative from the cells. The wood is then taken out of the cylinder.

Figure 2.1 CCA pressure treating processes (continued)
(Source:http://www.woodtreaters.com/WoodProducts/Pressure Treating/Process.asp)

2.1.2 General information on arsenic

Arsenic (As) is a naturally occurring element in the environment. The four major arsenic species of importance are the inorganic species, arsenite (As(III)) and arsenate (As(V)), and the organic species, monomethylarsonic acid (MMAA) and dimethylarsinic acid (DMAA). Toxicity among these species varies, and the inorganic species are generally more toxic. As(III) is also considered to be more mobile and toxic than As(V).

Arsenic has been used in several industries; it is used for the hardening of copper and lead alloys, in the pigmentation in paints and fireworks, and in the manufacturing of glass, cloth, and electrical semiconductors. Arsenic is also used extensively in the production of agricultural pesticides, which includes herbicides, insecticides, desiccants, wood preservatives, and feed additives. Arsenic in CCA and in treated wood products is predominantly in the +5 valence. Chemical and biological conditions in the environment affect the transformation between these different forms including the possible conversion to As(III), MMAA, and DMAA, Chemical conditions of importance include the pH and redox potential. Runoff from the arsenic leaching generated from industrial and agricultural wastes has resulted in increased levels of various forms of soluble arsenic in water. Inorganic arsenic is highly toxic to mammals and aquatic species. When ingested, it is readily absorbed from the gastrointestinal tract, the lungs, and to a lesser extent from the skin and is distributed throughout the body. Recently, arsenic in water supplies has been linked to arsenical dermatosis and skin cancer. Because of recent studies further revealing its toxicity, the United States Environmental Protection Agency (EPA) has classified arsenic as a human carcinogen (Group A) and has promulgated regulations lowering its maximum contaminant level in drinking water standards from its present requirement of 50 parts per billion (ppb) to 10 ppb in January 23, 2006 (EPA, 2008).

2.1.3 General information on chromium

Chromium (Cr) is a unique metal in that its two primary species in the environment have drastically different properties. Trivalent chromium (III) compounds are not usually considered health hazards; however, hexavalent chromium (VI) compounds can be toxic if orally ingested or inhaled. There are three main points to consider in chromium chemistry. First, the dominant naturally occurring form of chromium is trivalent oxide. The second is that the other valence form of chromium tends to convert to the trivalent oxide when it comes in contact with the natural environment. Hexavalent chromium tends to be reduced to trivalent chromium by organic matter, divalent iron, and sulfides. Lastly, trivalent chromium is very slow to react. Hexavalent chromium, however, can persist in the environment for long periods of time if it does not reduce to Cr(III).

2.1.4 General information on copper

Copper compounds usually have a valence of 2+ (II, cupric) under oxidized conditions or 1+ (I, cuprous) under reducing conditions. Only substances with the divalent (2+) form are used in CCA formulations. Copper is an essential element in mammals; it is incorporated into a large number of enzymes, particularly the oxidoreductases. There is a greated risk of adverse health effects from copper deficiency than from excess copper intake. The main sources of exposure to copper are from food and drinking water. The IPCS (1998) calculated that the average total intake of copper (i.e. food plus drinking water) in adults is between 1-2 mg/d, while it may occasionally reach 5 mg/d. Inhalation and dermal exposure to copper are considered to be insignificant, with inhalation exposure at 0.3-2.0 μg/d (IPCS, 1998). Due to the toxicology profile (APVMA, 2005) of copper and the high natural background exposure levels to copper in food and drinking water, the copper exposure risks to humans from the compounds present in dislodgeable residues from CCA-treated timber are considered to be negligible.

2.2 Composting

Composting is the biological decomposition and stabilization of organics substances, under conditions that allow the development of thermophillic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plant seeds, and can be beneficially applied to land. Thus, composting is a form of waste stabilization, yet, it is one that requires special conditions of moisture and aeration to produced thermophillic temperatures. The latter are generally considered to be above about 113ºF (45ºC). Maintenance of thermophillic temperatures is the primary mechanism for pathogen inactivation and seed destruction.

Most biological stabilization and conversion processes deal with dilute aqueous solutions, and only limited temperature elevations are possible. Thermophillic temperatures in aqueous solutions can be achieved if the substrate concentration is high and special provisions for aeration are employed. Aside from such special cases, composting is usually applied to solid or semisolid materials, making composting somewhat unique among the biological stabilization processes used in sanitary and biochemical engineering.

Aerobic composting is the decomposition of organic substrates in the presence of oxygen (air). The main products of biological metabolism are carbon dioxide, water, and heat. Anaerobic composting is the biological decomposition of organic substrates in the absence of oxygen. Metabolic end products of anaerobic decomposition are methane, carbon dioxide, and numerous low molecular weight intermediates such as organic acids and alcohols. Anaerobic composting releases significantly less energy per weight of organic decomposed compared to aerobic composting. Also, anaerobic composting has a higher odor potential because of the nature of many intermediate metabolites. For these reasons almost all engineered compost system are aerobic. Mass transfer limitations, however, may cause anaerobic zones in otherwise aerobic systems.

The objectives of composting have traditionally been to biologically convert putrescible organic materials into a stabilized form and to destroy organisms pathogenic to humans. Composting is also capable of destroying plant diseases, weed seeds, insects, and insect egg. Odor potential from compost is greatly reduced because the organics that remain after proper composting are relatively stable with low rates of decomposition. Composting can also effect considerable drying, which has particular value with wet substrates such as municipal and industrial sludges. The decomposition of substrate organics together with drying during composting can reduce the cost of the subsequent handling and increase the attractiveness of the compost for reuse or disposal.

Organic composts can accomplish a number of beneficial purposes when applied to the land. First, composts can serve as a source of organic matter for maintaining or building supplies of soil humus, necessary for proper soil structure and moisture holding capacity. Second, composts can improve the growth and vigor of crops in commercial agriculture and home related uses. Stable compost can reduce plant pathogens and improve plant resistance to disease. Colonization by beneficial microorganisms during the latter stages of composting appears to be responsible for inducing disease suppression. Third, compost contains valuable nutrients including nitrogen, phosphorus, and a variety of essential trace elements. The nutrient content of compost is related to the quality of the original organic substrate. However, most of composts are too low in nutrients to be classified as fertilizers. Their main use is as a soil conditioner, mulch, top dressing, or organic base with fertilizer amendments. On the other hand, nutrients such as nitrogen are organically bound and slowly released throughout the growing season, making them less susceptible to loss by leaching than soluble fertilizers.

2.2.1 Role of microorganisms

Composting is a succession of microbial activities whereby the environment created by one group of microorganisms invites the activity of successor groups. Different types of microorganisms are therefore active at different times in the composting pile. Bacteria have the most significant effect on the decomposition process, and are the first to take hold in the composting pile, processing readily decomposable nutrients (primarily proteins, carbohydrates, and sugars) faster than any other type of microorganism. Fungi, which compete with bacteria for food, play an important role later in the process as the pile dries, since fungi can tolerate low-moisture environments better than bacteria. Some types of fungi also have lower nitrogen requirements than bacteria and are therefore able to decompose cellulose materials, which bacteria cannot. Because fungi are active in composting piles, concern has arisen over the growth of opportunistic species, particularly those belonging to the genus *Aspergillus*.

Macroorganisms also play a role in the composting process. Rotifers, nematodes, mites, springtails, sowbugs, beetles, and earthworms reduce the size of the composting feedstock by foraging, moving in the compost pile, or chewing the composting materials, creating greater surface areas and sites for microbial action to occur.

The microorganisms necessary for composting are naturally present in most organic materials, including leaves, grass clippings, and other yard trimmings, and other organic materials. Products are available that claim to speed the composting process through the introduction of selected strains of bacteria, but tests have shown that inoculating compost piles in this manner is not necessary for effective composting of typical yard trimmings or MSW feedstock (Rynk et al., 1992; Haug, 1980; Gray et al., 1971)

The bacteria and fungi important in decomposing feedstock material can be classified as mesophilic or thermophilic. Mesophilic microorganisms or mesophiles (those that grow best at temperatures between 25 ºC and 45ºC) are dominant throughout the composting mass in the initial phases of the process when temperatures are relatively low. These organisms use available oxygen to transform carbon from the composting feedstock to obtain energy, and, in so doing, produce carbon dioxide (CO_2) and water. Heat also is generated as the microorganisms metabolize the composting feedstock. As long as the compost pile is of sufficient size to insulate internal layers from ambient temperatures and no artificial aeration or turning occurs, most of the heat generated by the microorganisms will be trapped inside the pile. In the insulated center layers, temperatures of the composting mass will eventually rise above the tolerance levels of the mesophilic organisms. Figure 2.2 shows a typical temperatures pattern for a natural composting process. When the temperatures near 45ºC (113 ºF), mesophiles die or become dormant, waiting for the condition to reverse.

At this time, thermophilic microorganisms or thermophiles (those that prefer temperatures between 45 ºC and 70ºC) become active, consuming the materials readily available to them, multiplying rapidly, and replacing the mesophiles in most sections of the composting pile. Thermophiles generate even greater quantities of heat than do mesophiles, and the temperatures reached during this time are hot enough to kill most pathogens and weed seeds. Many composting facilities maintain a temperature of 55ºC in the interior of the compost pile for 72 hours to ensure pathogen destruction and to render weeds unviable.

The thermophiles continue decomposing the feedstock materials as long as nutrient and energy sources are plentiful. As these sources become depleted, however, thermophiles die and the temperature of the pile drops. Mesophiles then dominate the decomposition process once again until all readily available energy sources are utilized

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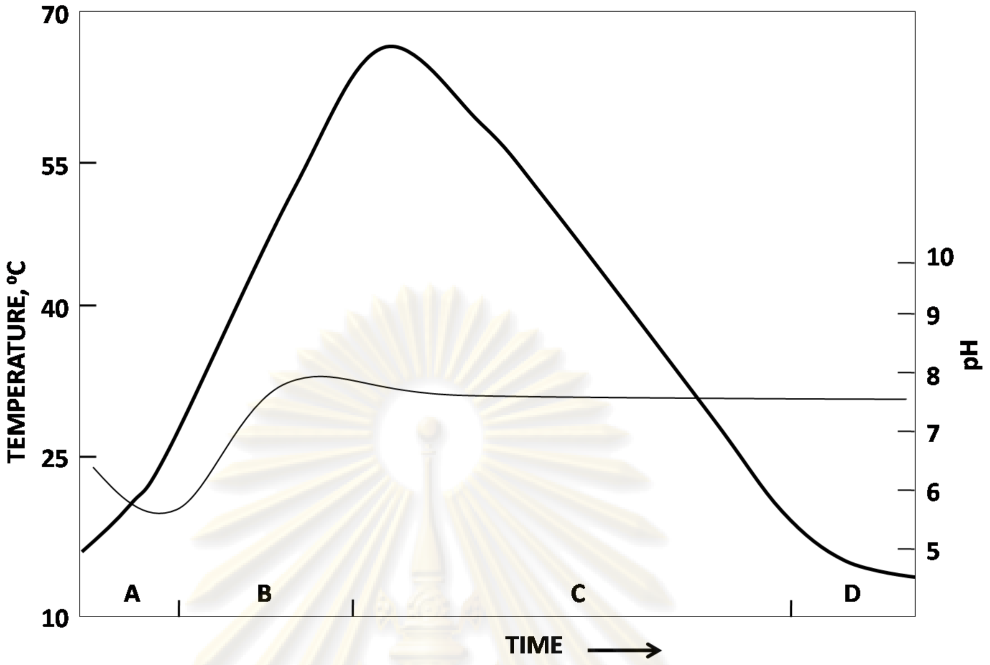


Figure 2.2 Temperature and pH variation with time: phases of microbial activity.
A = mesophliic, B = thermophilic, C = cooling, D = maturing.
Source (Grey *et al.*, 1971)

2.2.2 Factor influencing the composting process

Because microbes are the key active agents in composting, it follows that the factors that affect their proliferation and activity are those which determine the rate and extent of composting. Collectively, they are environmental in nature. The substrate is one of the more important of the factors. Substrate-related factors include the carbon-nitrogen ratio (C:N), particle size, oxygen availability, aeration, moisture content, temperature, and pH. Of the preceding, the chemical and physical nature of the substrate and aeration are especially important in process design. The C:N ratio, particle size, moisture content, and pH are all aspects of the nature of the substrate, which is used to refer primarily to the composition and availability of macro- and micronutrients in the substrate. Any changes in these factors are interdependent; a change in one parameter can often result in change in other. A simplified diagram showing the major inputs and outputs of the composting process is given in Figure.2.3

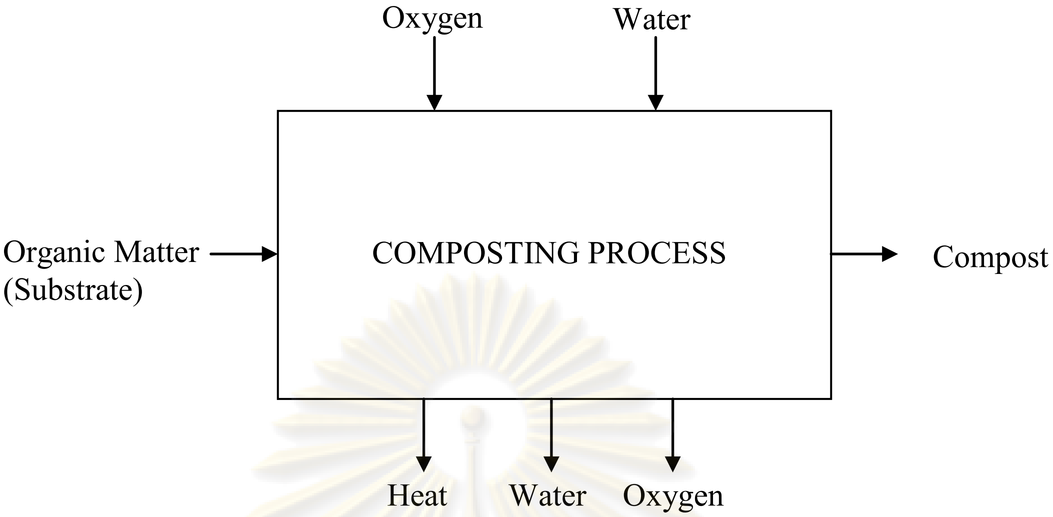


Figure 2.3 Input-output analysis of the composting process

2.2.2.1 Nutrients levels and balance

For composting to proceed efficiently, microorganisms require specific nutrients in their available forms, adequate concentrations, and proper ratios. The essential macronutrients needed by microorganisms in relatively large amounts include carbon (C), nitrogen (N), phosphorous (P), and potassium (K). Microorganisms require C as an energy source. They also need C and N to synthesize protein, build cells, and reproduce. P and K are also essential for cell production and metabolism. In a composting system, either C or N is usually the limiting factor for efficient decomposition. (Richard, 1992)

Composting organisms also need micronutrients, or trace elements, in minute amounts to foster the proper assimilation of all nutrients. The primary micronutrients needed include cobalt, manganese, magnesium, copper, calcium, boron, chloride, iron, molybdenum, selenium, sodium, and zinc (Boyd, 1984). While these nutrients are essential for life, micronutrients present in greater than minute amounts can be toxic to composting microorganisms.

Even if these nutrients are present in sufficient amounts, their chemical form might make them unavailable to some or all microorganisms. Microorganisms' ability to use the available organic compounds present depends on their microorganism's "enzymatic machinery" (Boyd, 1984). Some microorganisms cannot use certain forms of nutrients because they are unable to process them. Large molecules, especially those with different types of bonds, cannot be easily broken down by most microorganisms, and this slows the decomposition process significantly. As a result, some types of feedstock break down more slowly than others, regardless of the composting conditions (Grey *et al.,* 1971). For example, lignin (found in wood) or chitin(present in shellfish exoskeletons) are very large, complex molecules and are not readily available to microorganisms as food. These materials therefore decompose slowly.

The C:N ratios is a common indicator of the availability of compounds for microbial use. The measure is related to the proportion of carbon and nitrogen in the microorganisms themselves.

High C:N ratio (i.e., high C and low N level) inhibit the growth of microorganisms that degrade compost feedstock. Low C:N ratios (i.e., low C and high N levels) initially accelerate microbial growth and decomposition. With this acceleration, however, available oxygen is rapidly depleted and anaerobic, foul-smelling conditions result if the pile is not aerated properly. The excess N is released as ammonia gas. Extreme amounts of N in a composting mass can form enough ammonia to be toxic to the microbial population, further inhibiting the composting process (Grey *et al.,* 1971b; Haug, 1980). Excess N can also be lost in leachate, in either nitrate, ammonia, or organic forms (Richard, 1992). However, carbon and nitrogen might not be present in proportions that allow them to be used efficiently by microorganisms. Composting proceeds most efficiently when the C:N ratio of the composting material is from 25:1 to 35:1. When the C:N ratio is greater than 35:1, the composting process slows down. When the ratio is less than 25:1, there can be odor problems due to an aerobic condition, release of ammonia, and accelerated decomposition.

Generally, the C:N ratio can be approximated by examining the nature of the feedstock; green vegetation is high in nitrogen and brown vegetation is high in carbon. While the diversity of MSW feedstock materials makes an estimation of the C:N ratio somewhat difficult, a precise C:N ratio can be determined by laboratory analysis. Feedstock materials with different C:N ratios can be mixed to obtain optimal levels of carbon and nitrogen when necessary. Table 2.3 shows the carbon to nitrogen ratio of various materials.

Table 2.3 Carbon-to-nitrogen ratio of various materials (Golueke, 1977; Richard *et al.,* 1990; Grey *et al.,* 1971b)

Type of feedstock	Ratio	Type of feedstock	Ratio
High carbon content		**High nitrogen content**	
- Bark	100-130:1	- Cow manure	18:1
- Corn Stalks	60:1	- Food scraps	15:1
- Foliage	40-80:1	- Fruit scraps	35:1
- Leaves and weeds(dry)	90:1	- Grass clippings	12-20:1
		- Hay (dry)	40:1
- Mixed MSW	50-60:1	- Horse manure	25:1
- Paper	170:1	- Humus	10:1
- Sawdust	500:1	- Leaves (fresh)	30-40:1
- Straw (dry)	100:1	- Mixed grasses	19:1
- Wood	700:1	- Nonlegume vegetable scraps	11-12:1
		- Poultry manure	15:1
		- Biosolids	11:1
		- Weeds (fresh)	25:1
		- Seaweed	19:1

2.2.2.2 Oxygen

Composting can occur under aerobic (requiring free oxygen) or anaerobic (without free oxygen) conditions, but aerobic composting is much faster (10-20 times faster) than anaerobic composting. Anaerobic composing also tends to generate more odors because gases such as hydrogen sulfide and amines are produced. Methane also is produced in the absence of oxygen.

Microorganisms important to the composting process require oxygen to break down the organic compounds in the composting feedstock. Without sufficient oxygen, these microorganisms will diminish, and anaerobic microorganisms will take their place. This occurs when the oxygen concentration in the air within the pile falls below 5 to 15 percent (ambient air contains 21 percent oxygen). To support aerobic microbial activity, void spaces must be present in the composting materials. These voids need to be filled with air. Oxygen can be provided by mixing or turning the pile, or by using forced aeration systems.

The amount of oxygen that needs to be supplied during composting depends on in following:

- The stage of the process.

  Oxygen generally needs to be supplied in the initial stages of composting; it usually does not need to be provided during curing.

- The type of feedstock.

  Dense, nitrogen-rich materials (e.g., grass clippings) will require more oxygen.

- The particle size of the feedstock.

  Feedstock materials of small particle size (e.g., less than 1 or 2 inches in diameter) will compact, reducing void spaces and inhibiting the movement of oxygen. For this reason, the feedstock should not be shredded too small before processing

- The moisture content of the feedstock

  Materials with high moisture content (e.g., food scraps, garden trimmings) will require more oxygen.

Care must be taken, however, not to provide too much aeration, which can dry out the pile and impede composting.

2.2.2.3 Particle size

The particle size of the feedstock affects the composting process. The size of feedstock materials entering the composting process can vary significantly. In general, the smaller the shreds of composting feedstock, the higher the composting rate. Smaller feedstock materials have greater surface areas in comparison to their volumes. This means that more of the particle surface is exposed to direct microbial action and decomposition in the initial stages of composting. Smaller particles within the composting pile also result in a more homogenous mixture and improve insulation (Grey *et al.,* 1971b). Increased insulation capacity helps maintain optimum temperatures in the composting pile. At the same time, however, the particles should not be so small as to compact too much, thus excluding oxygen from the void spaces, as discussed above.

2.2.2.4 Moisture

The moisture content of a composting pile is interconnected with many other composting parameters, including the moisture content of the feedstock, microbial activity within the pile, oxygen levels, and temperature. Microorganisms require moisture to assimilate nutrients, metabolize new cells, and reproduce. They also produce water as part of the decomposition process. If water is accumulated faster than it is eliminated via either aeration or evaporation (driven by high temperatures), then oxygen flow is impeded and anaerobic conditions result (Gray *et al.,* 1971). This usually occurs at a moisture level of about 65 percent (Rynk *et al.,* 1992)

Water is the key ingredient that transports substances within the composting mass and makes the nutrients physically and chemically accessible to the microbes. If the moisture content level drops below about 40-45 percent, the nutrients are no longer in an aqueous medium and easily available to the microorganisms. Their microbial activity decreases; thus decreasing and the composting process. Below 20 percent moisture, very little microbial activity occurs (Haug, 1980) and, rewetting might be required (Richard, 1992). Maintaining moisture content within a 40 to 60 percent range can significantly enhance the composting process. For high-rate MSW composting, a minimum moisture content of 50 to 55 percent is recommended (Golueke, 1997). MSW compost mixtures usually start at about 55 percent moisture and dry to 35 percent moisture (or less) prior to final screening and marketing (CC, 1991).

Mechanical aeration and agitation directly influence the moisture content of a composting pile. Aeration increases flow through the composting pile, inducing evaporation from the interior spaces. Turning composting piles exposes the interior of the piles, releasing heated water as stream. Finally, temperature determines how much moisture will be lost with turning and aeration; the higher the temperature, the more water will be lost via evaporation, in turn, moisture loss affects the temperature of the piles.

2.2.2.5 Temperature

Temperature is a critical factor in determining the rate of decomposition that takes place in a composting pile. Composting temperatures largely depend on how the heat generated by the microorganisms is offset by the heat lost through controlled aeration, surface cooling, and moisture losses (Richard, 1992a). The most effective composting temperatures are between 45 ºC and 59 ºC (Richard, 1992a). If temperatures are less than 20ºC, the microbes do not proliferate and decomposition slows. If temperatures are greater than 59 ºC, some the microorganisms are inhibited or killed, and reduced diversity of organisms results in lower rates of decomposition (Finstein *et al.,* 1986; Storm, 1985).

Microorganisms tend to decompose materials most efficiently at the higher ends of their tolerated temperature ranges. The rate of microbial decomposition therefore increases as temperatures rise until an absolute upper limit is reached. As a result, the most effective compost management plan is to maintain temperatures at the highest level possible without inhibiting the rate of microbial decomposition (Richard, 1992a; Rynk *et al.,* 1992). The relation between the role of microorganisms and the temperature fluctuation is shown in Figure 2.2 above.

2.2.2.6 Acidity/Alkalinity (pH)

The pH of a substance is a measure of its acidity or alkalinity (a function of the hydrogen ion concentration), described by a number ranging from 1 to 14. A pH of 7 indicates a neutral substance, whereas a substance with a pH level below 7 is considered to be acidic, and a substance with a pH higher than 7 is alkaline. Bacteria prefer a pH between 6 and 7.5. Fungi thrive in a wider range of pH levels than bacteria, in general preferring a pH between 5.5 and 8 (Boyd, 1984). If the pH drops below 6, microorganisms, especially bacteria, die off and decomposition is slowed (Wiley, 1956). If the pH reaches 9, nitrogen is converted to ammonia and becomes unavailable to organisms (Rynk *et al.,* 1992). This too slows the decomposition process.

Like temperatures, pH levels tend to follow a success pattern through the composting process. Figure 2.2 shows the progression of pH over time in a composting pile. As is illustrated, most decomposition takes place between pH 5.5 and 9 (Rynk *et al.,* 1992; Gray *et al*., 1971b). During the start of composting process, organics acids typically are formed and the composting materials usually become acidic a pH of about 5. At this point, the acid-tolerating fungi play a significant role in decomposition. Microorganisms soon break down the acids, however, and the pH levels gradually rise to a more neutral range, or even as high as 8.5. The role of bacteria in composting increases and they become predominant again as the pH level rises. If the pH does rise, this could be an indication that the compost product is not fully matured or cured.

2.2.3 Composting methods

Microorganisms decompose the readily available nutrients present in the feedstock during composting. Because most of the actual change in the feedstock occurs during this stage, the most intensive methods and operations tends to be used. Compost processing can occur in simple environments that are completely subject to external forces or in complex and highly controlled environments.

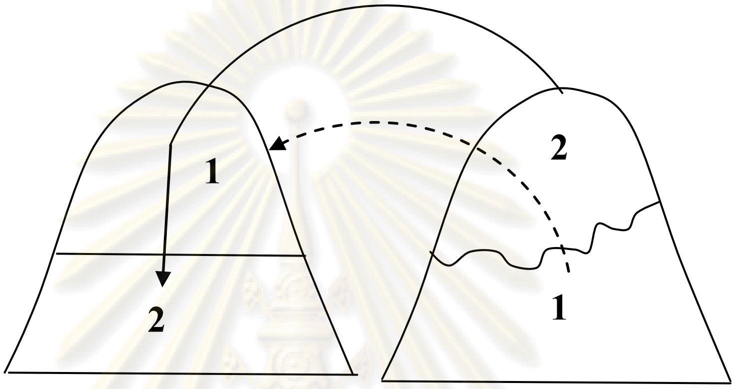
The composting methods currently employed are as follows: Passive piles, Turned windrows, Aerated static piles, and In-vessel systems

2.2.3.1 Passive piles

Although this method is simple and generally effective, it is not applicable under all conditions or to all types of materials. Composting under these conditions is very slow and is the best suited for materials that are relatively uniform in particle size. Although passive piles theoretically can be used for composting either yard trimmings or MSW, the propensity for odor problems renders them unsuitable for MSW feedstock materials or even large quantities of grass or other green materials that have high nitrogen content.

Passive piles require relatively low inputs of labor and technology. They consist of piles of composting material that are tended relatively infrequently, usually only once each year. Tending the piles entails turning them (i.e., physically tearing down and reconstructing them). Figure 2.4 illustrates the proper method of turning a compost pile. Such an effort requires only a few days use of personnel and equipment, making this a relatively low-cost composting method.

Lift the compost high with a bucket loader and let the compost fall to a new location to create a cascading mixing effect.



Note: The principle of the mixing technique is to move the top of the pile to the bottom of the pile being formed, mixing the materials well during this process

Figure 2.4 Pile turning for aeration and mixing (UConn CES, 1989)

Before piles are turned, the moisture content of internal and external layers of the compost pile should be checked using the methods discussed in the preprocessing section of this chapter. If the moisture content is too low, water can be added by manually spraying the pile with hoses or by using automatic sprinklers or irrigation systems. If the moisture content is too high, turning can be conducted more frequently to increase evaporation rates.

With all composting methods, regular monitoring of the temperatures of the composting materials is recommended. A variety of long-stem (1m) digital and dial-type thermometers and infrared scanners are available that can read temperatures up to 93ºC.

Passive piles should be constructed large enough to conserve sufficient heat but not so large as to overheat. If temperatures of the composting mass exceed 60ºC, composting materials can combust, and/or microorganisms needed for decomposition can be killed. Compost piles should be turned if this temperature is exceeded.

Even if temperature and moisture are not monitored with the passive pile composting method, the periodic turning of the piles will adjust the oxygen level, moisture content, and temperature to some degree. The movement created by turning aerates the pile, and the anaerobic center is replaced with oxygen-rich external layers of the material. In addition, dry internal materials are exposed to the outer layers of the pile where they are more susceptible to wetting by rain or snow. The increased aeration and wetting caused by turning also serve to reduce temperatures in the internal layers, preventing excessive heat buildup. Temperature and oxygen levels also can be reached. The larger the pile, however, the lower the degree of oxygen penetration and the greater the potential for anaerobic conditions forming in the center of the pile. Several disadvantages are associated with passive pile methods. Unlike more intensive composting processes that can produce a finished product in a few weeks to a few months, passive piles can require over 1 year for the composting process to complete. In addition, the minimal turning of passive piles results in the formation of anaerobic conditions so that when piles are eventually turned (especially for the first year or two of the process) significant odors result. Passive piles consequently cannot be placed in densely populated areas, and a large buffer zone is recommended between residents and composting operations (Storm and Finstein, 1989). The untended passive piles also might attract discard trash at the site. Some means for controlling access to a passive pile site is, therefore, recommended. Finally, large, untended piles have the potential to overheat and combust, creating a possible fire hazard.

2.2.3.2 Turned windrows

Turned windrows are a widely used method for composting yard trimmings and MSW. This method generally is not appropriate, however, for MSW containing significant amounts of putrescible materials due to odor concerns.

Turned windrows are elongated composting piles that are turned frequently to maintain aerobic composting condition. The frequent turning promotes uniform decomposition of composting materials as cooler outer layers of the compost pile are moved to inner layers where they are exposed to higher temperatures and more intensive microbial activity. Composting yard trimmings using the turned windrow method takes approximately 3 months to 1 year.

Turned windrow operations generally can be conducted outdoors. To increase the operator's ability to control composting conditions, however, windrows can be placed under or inside shelters. Leachate problems should be minimized by constructing windrows on firm surfaces surrounded by vegetative filters or trenches to collect runoff. A paved surface might be helpful, depending on the size and location of the facility and how muddy it might get. Run-on controls also are helpful as is the careful balancing of C:N ratio. Progressive decomposition of the composting materials reduces the size of the windrows, allowing them to be combined to create space for new windrows or other processes.

As with passive piles, forming windrows of the appropriate size helps maintain appropriate temperature and oxygen levels. The ideal height for windrows is from 5 to 6 feet (CRS, 1989). This height allows the composting materials to be insulated properly but prevents the buildup of excessive heat. Windrow heights vary, however, based on the feedstock, the season, the region in which the composting operation is being conducted, the tendency of the composting materials to compact, and the turning equipment that is used. Windrows widths generally are twice the height of the piles. Factors such as land availability, operating convenience and expedience, the type of turning equipment used, and the end product quality also affect windrow width selection. Careful monitoring of the width is unnecessary, however, to ensure that proper oxygen and temperature levels are maintained; windrow height determines aeration levels to a far greater degree than windrow width. Windrow length also has little impact on the composting process.

Windrow shapes can be altered to help maintain appropriate composting conditions (primarily moisture levels). For example, windrows with concave crests are appropriate during dry periods and when the moisture content of the composting materials is low to allow precipitation to be captured more efficiently. Peaked windrows are preferable during rainy periods to promote the runoff of excess water and to prevent saturation. Illustrations of these windrow shapes are presented in Figure 2.5.

Turning frequencies for this method can range from twice per week to once per year. In general, the more frequently that the piles are turned, the more quickly the composting process is completed. Some materials do not need to be turned as frequently to maintain high levels of decomposition.

The windrow composting system is showed in Figure 2.5

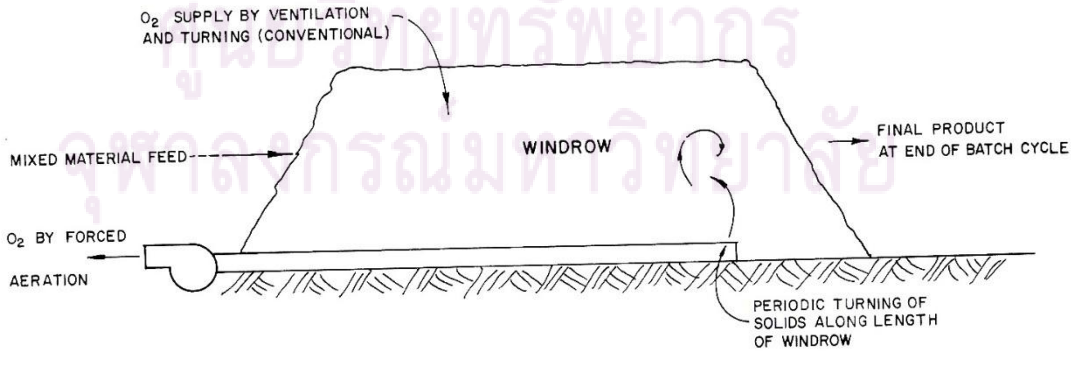


Figure 2.5 The windrow composting system (Rynk *et al.,* 1992)

2.2.3.3 Aerated static piles

Aerated static piles, sometimes called forced aeration windrows, are a relatively high-technology approach that can be used to compost yard trimming and MSW. This approach is effective when space is limited and the composting process must be completed within a year. In this method, piles or windrows are placed on top of a grid of perforated pipes. Fans and blowers pump or pull air through the pipes and, consequently, through the composting materials. This maintains aeration in the compost pile, minimizing or eliminating the need for turning. In some operations, the pipes are removed after 10 to 12 weeks of composting and the pipes or windrows are then turned periodically.

Aerated static piles are 10 to 12 feet high on average. To facilitate aeration, wood chips (or other porous materials) are spread over the aeration pipes at the base of the pile. The feedstock is then added on top of the wood chips. It might be necessary to top off the pile with a layer of finished compost or bulking agent. This protects the surface of the pile from drying, insulates it from heat loss, discourage flies, and filters ammonia and potential odors generated within the pile (Rynk *et al.,* 1992). It can take as little as 3 to 6 months to produce finished compost with this method.

Air can be supplied to the process through a suction system or a positive pressure system. The suction system draws air into and through the pile. The air then travels through a perforated pipe and is vented through a pile of finished compost, which acts as an odors filter. With this system, condensate from water vapor drawn from the pile must be removed before the air reaches the blower. The ability to contain exhaust gases for odor treatment is an important advantage of suction aeration.

The positive pressure aeration system uses a blower to push air into the compost pile. The air travels through the pile and is vented over its entire surface. Because of the way air is vented, odor treatment is difficult with positive pressure aeration. The absence of an odor filter, however, means lower pressure losses with this system, which results in greater air flow from the same blower power. Therefore, positive pressure systems can be more effective at cooling the pile and are preferred when warm temperatures are a major concern (Rynk *et al.*, 1992).

To ensure that decomposition proceeds at high rates. Temperature and oxygen levels must be closely monitored and maintained with aerated static pile composting. Aeration management depends on how the blower is controlled. The blower can be run continuously or intermittently. Continuous operation of the blower permits lower air flow rates because oxygen and cooling are supplied constantly; however, this leads to less uniform pile temperatures intermittent operation of the blower is achieved with a programmed timer or a temperature feedback system. Timers are a simple and inexpensive method of controlling blowers to provide enough air to satisfy oxygen requirements and control temperatures. This approach does not always maintain optimum temperatures, however. A temperature feedback system does attempt to maintain optimum temperatures, for example, within the range of 54ºC to 60ºC (Rynk *et al.*, 1992).

In general, the aerated static pile method is best suited for granular and relatively dry feedstock materials that have a relatively uniform particle size of less than 1.5 to 2 inches in diameter. This is because large or wet materials and materials of diverse sizes have a tendency to clump. Clumping constricts air flow through the pile, leads to short circuits of air pumping equipment, produces anaerobic pockets, and otherwise limits the rate of decomposition. Aerated static piles are commonly used for composting wet materials (such as biosolids), however. Clumping is controlled by proper mixing of bulky materials that adjust porosity and moisture.

The aerated static pile system is illustrated in Figure 2.6

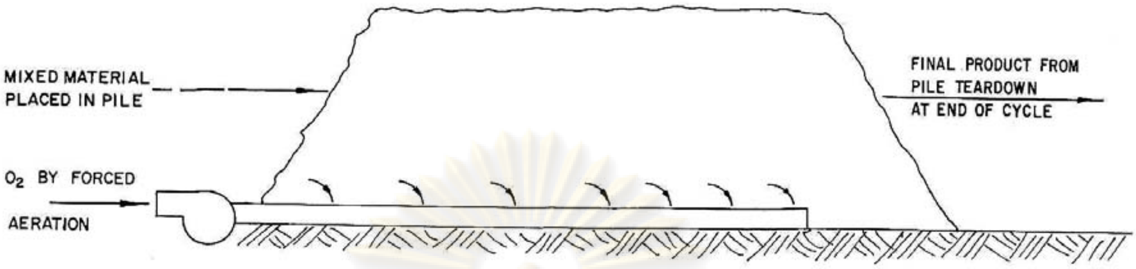


Figure 2.6 The aerated static pile system (Rynk *et al.,* 1992)

2.2.3.4 In-vessel system

In an in-vessel systems high-technology employed to compost materials within a fully enclosed system. All critical environment conditions are mechanically controlled with this method, and, as with most in-vessel systems, they also are fully automated. An in-vessel system is effectively for MSW if : (i) the composting finishes rapidly, (ii) odor and leachate is handled carefully, (iii) space is limited, and (iv) sufficient resources are available. These systems are rarely used to compost because they are expensive to maintain properly.

In-vessel technologies range from relatively simple to extreme complex systems. Two broad categories of in-vessel technologies are available: rotating drum and tank systems. Rotating drum systems rely on a tumbling action to continuously mix the feedstock materials. Figure 2.7 illustrates a rotating drum composter. The drums typically are long cylinders, approximately 9 feet in diameter, which are rotated slowly, usually at less than 10 revolutions per minute (CRS, 1989). Oxygen is forced into the drums through nozzles from exterior air pumping systems. The tumbling of the materials allows oxygen to be maintained at high and relatively uniform levels throughout the drum. The promotional literature for rotating drums indicates that composting materials must be retained in the drums for only 1 to 6 days

(CRS, 1989). Complete stabilization of the composting materials is not possible within this timeframe, however, and 1 to 3 months of further composting and curing is necessary (CRS, 1989).

Tank in-vessel systems are available in horizontal or vertical varieties. Rectangular tanks are one type of horizontal in-vessel system in which aeration is accomplished through the use of external pumps that force air through the perforated bottom of the tanks. Mixing is accomplished by mechanically passing a moving belt, paddle wheel, or flail-covered drum through the composting materials. This agitates the material, breaks up clumps of particles, and maintains porosity. Composting materials are retained in the system for 6 to 28 days and then cured in windrows for 1 to 2 months.

The agitated-bed system is an example of this type of horizontal in-vessel system. Figure 2.8 illustrates a rectangular agitated-bed composting system. Composting takes place between walls that form long, narrow channels (called *beds*). A rail or channel on top of each wall supports and guides a compost-turning machine. Feedstock is placed at the front end of the bed by a loader, and the turning machine mixes the composting materials and discharges it behind the machine as the material moves forward on rails. An aeration system in the floor of the bed supplies air and cools the composting materials. In commercially available systems, bed widths range from 6 to 20 feet, and bed depths are between 3 and 10 feet. Suggested composting periods for commercial agitated-bed systems range from 2 to 4 weeks (Rynk *et al.*, 1992).

Vertical tank-vessel systems use a vertical tank orientation. Forced aeration and stirring also are used with this method. These systems can consist of a number of tanks dedicated to distinct stages of the composting process or of one tank (which might be divided into different “floors”). Vertical tank in-vessel systems might use conveyors, rotating screws, air infeeds, or air outfeeds to agitate compost, move compost between tanks, and maintain proper levels of oxygen and moisture. A problem with vertical tank in-vessel is the difficulty of maintaining an equilibrium of moisture and air between each of the layers inside the tank. In an attempt to adequately aerate the top layers of the compost, these systems can cool down the bottom layers of compost. Furthermore, excessive condensation can form at the top of vertical tanks where moisture and temperature levels are uncontrollable.

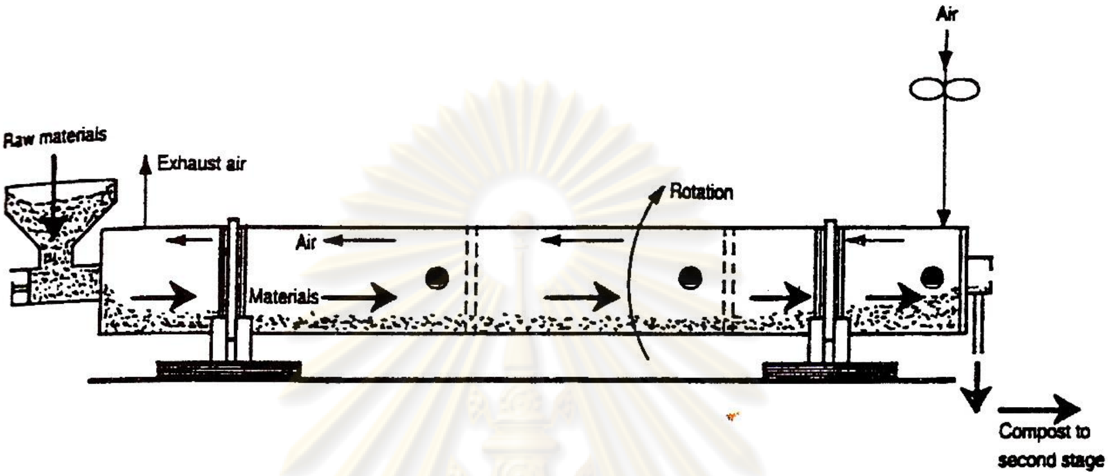


Figure 2.7 A rotating drum composter (Rynk *et al.,* 1992)

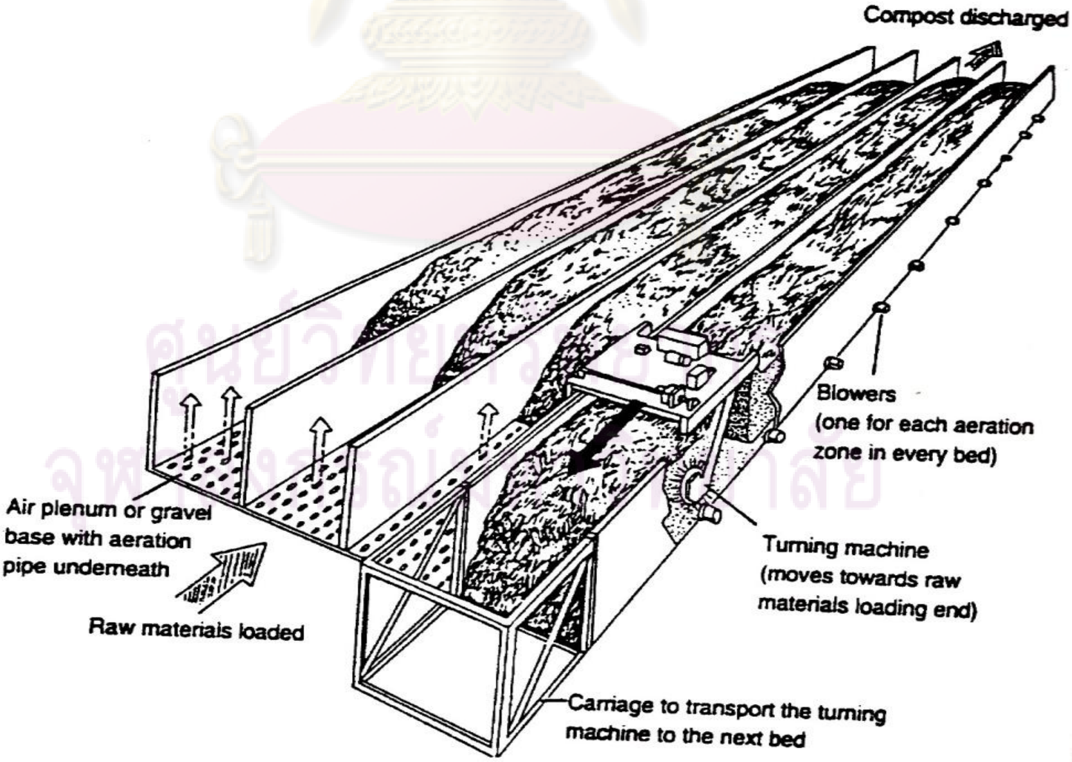


Figure 2.8 A rectangular agitated-bed composting system (Rynk *et al.,* 1992)

2.3 Bioavailability

Metals of major interest in bioavailability studies, as listed by the U.S. Environmental Protection Agency (EPA), are Al, As, Be, Cd, Cr, Cu, Hg, Ni, Pb, Se, and Sb (McKinney and Rogers, 1992). Other metals that are presently of lesser interest to the EPA are Ag, Ba, Co, Mn, Mo, Na, Tl, V, and Zn. These metals were selected because of their potential for human exposure and increased health risk.

Metals can be dispersed in soil, water, and air. Geoscientists are mainly concerned with metals dispersed in soil and sediment, dissolved in ground and surface water, suspended as particles in surface water, and pore fluid in sediment. The interrelationships of man, metals, and the environment are shown in Figure 2.9 below.

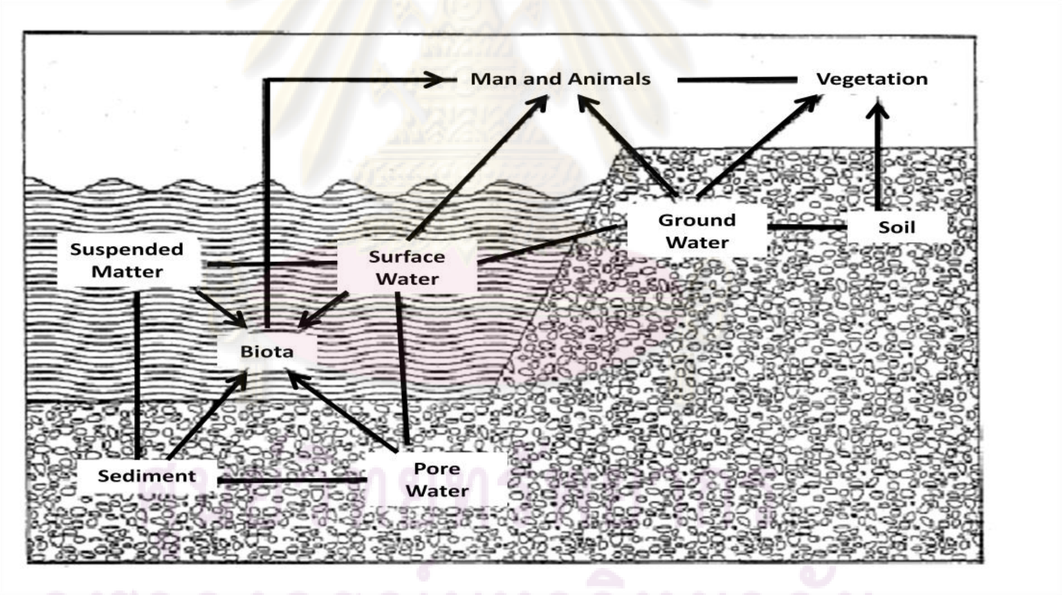


Figure 2.9 The interrelationships of man, metals, and the environment (Salomons and Forstner, 1988)

In addition, metals can be dispersed into the atmosphere, by natural geochemical cycling by other anthropogenic processes (such as smelting and burning leaded gasoline and coal) and by microbial activities; these metal fluxes must be considered in overall metal bioavailability studies. Bioaccumulation of metals by biota in surface water and by plants and animals in terrestrial environments can adversely affect humans. In surface and ground water, sediment and air, bioavailability is a complex function of many factors including total concentration and speciation (physical-chemical forms) of metals, mineralogy, pH, redox potential, temperature, total organic content (both particulate and dissolved fractions), and suspended particulate content, as well as volume of water, water velocity, and duration of water availability, particularly in arid and semi-arid environments. In addition, wind transport and removal from the atmosphere by rainfall (frequency is more important than amount) must be considered. Many of these factors vary seasonally and temporally, and most factors are interrelated. Consequently, changing one factor may affect several others. In addition, generally poorly understood biological factors seem to strongly influence the bioaccumulation of metals and severely inhibit metal bioavailability predictions (Luoma, 1989).

In order to understand bioavailability, plant materials and selective chemical leaches of soil must be analyzed and the results compared. Elemental suites for which analyses are performed and the type of selective leaches utilized must be tailored to bedrock and soil types, and to suspected anthropogenic inputs. Soil pH, organic matter, and sulfur and carbonate contents should be determined to enable accurate assessments of elemental reservoirs, mobility, and bioavailability. Additional work on mineralogical residences of metals is also important because metals can be associated with several sites (see Figure.2.10).

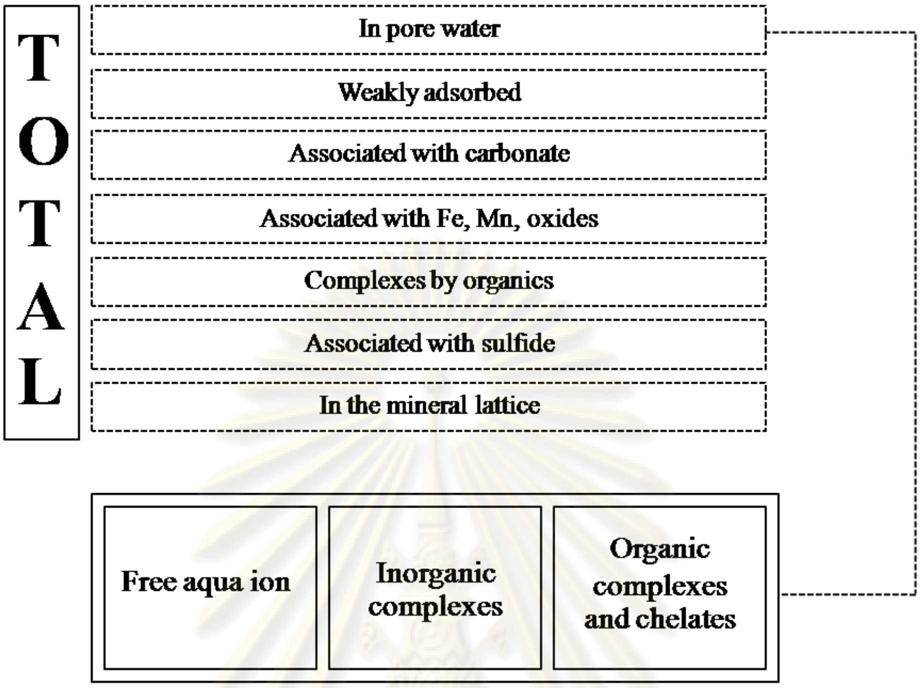


Figure 2.10 The chemical forms of metals in solid phases. (Gunn *et al.,*1988).

2.3.1 Factors that influence the partitioning of metals in the environment

After discharge to an aquatic environment but before uptake by organisms, metals are partitioned between solid and liquid phases. Within each phase, further partitioning occurs among ligands as determined by ligand concentrations and metal-ligand bond strengths. In solid phases, soil, sediment, and surface water particulates, metals may be partitioned into six fractions: (1) dissolved, (2) exchangeable, (3) carbonate, (4) iron-manganese oxide, (5) organic, and (6) crystalline (Elder, 1989; Salomons, 1995). Various metals partition differently among these fractions as shown by sequential partial extraction procedures. Partitioning is affected strongly by variations in the pH, the redox state, the organic content, and other environmental factors (Elder, 1989; Salomons, 1995). The relative mobility and bioavailability of trace metals associated with different fractions are shown in Table 2.4.

Table 2.4 Relative mobility and availability of trace metals (Salomons, 1995)

Metal species and association	Mobility
Exchangeable (dissolved) cations	High - Change in the major cationic composition (e.g. in an estuarine environment) may cause a release due to ion exchange
Metals associated with Fe-Mn oxides	Medium - Change in redox conditions may cause a release but some metals will precipitate if the sulfide mineral present is insoluble
Metals associated with organic matter	Medium/High - With time, decomposition/oxidation of the organic matter occurs
Metals associated with sulfide minerals	Strong - Dependent on environmental conditions. under oxygen-rich conditions, oxidation of sulfide minerals leads to the release of metals
Metal fixed in the crystalline phase	Low - Only available after weathering and decomposition

The dissolved fraction consists of carbonate complexes, whose abundance is depend on the pH, and metals in solution, including the metal cation and anion complexes and hydrated ions whose solubilities are affected strongly by pH and tend to increase with decreasing pH (Elder, 1989). Exchangeable fractions consist of metals bound to colloidal or particulate material. Metals associated with carbonate minerals in sedimentary rocks and soil constitute the carbonate fraction, which can be newly precipitated in soil. The iron-manganese oxide fraction consists of metals adsorbed to iron-manganese oxide particles or coatings. The organic fraction consists of metals bound to various forms of organic matter. The crystalline fraction consists of metals contained within the crystal structure of minerals and normally not available to biota.)

Hydrogen ion activity (pH) is probably the most important factor governing metal speciation, solubility from mineral surfaces, transport, and eventual the bioavailability of metals in aqueous solutions. pH affects both the solubility of metal hydroxide minerals and adsorption-desorption processes. Most metal hydroxide minerals have very low solubilities under pH conditions in natural water. Because hydroxide ion activity is directly related to pH, the solubility of metal hydroxide minerals increases with decreasing pH, and more dissolved metals become potentially available for incorporation in biological processes as pH decreases. Ionic metal species also are commonly the most toxic form to aquatic organisms (Salomons, 1995).

Adsorption, which occurs when dissolved metals are attached to surfaces of particulate matter (notably iron, manganese, and aluminum oxide minerals, clay, and organic matter), is also strongly dependent on pH and, of course, the availability of particulate surfaces and total dissolved metal content (Bourg, 1988; Elder, 1989). Metals tend to be adsorbed at different pH values, and sorption capacity of oxide surfaces generally varies from near 0 percent to near 100 percent over a range of about 2 pH units.

The adsorption edge, the pH range over which the rapid change in sorption capacity occurs, varies among metals, which results in precipitation of different metals over a large range of pH units. Consequently, mixing metal-rich, acidic water with higher pH, metal-poor water may result in the dispersion and separation of metals as different metals are adsorbed onto various media over a range of pH values. Cadmium and zinc tend to have adsorption edges at higher pH levels than those of iron and copper, and consequently they are likely to be more mobile and more widely dispersed. Adsorption edges also vary with the concentration of the complexing agent; thus, increasing concentrations of the complexing agent increases the pH of the adsorption edge (Bourg, 1988). Major cations such as Mg^{+2} and Ca^{+2} also compete for adsorption sites with metals and can reduce the amount of metal adsorption (Salomons, 1995).

Particulate size and the resulting total surface area available for adsorption are both important factors in adsorption processes and can affect metal bioavailability (Luoma, 1989). Small particles with large surface-area-to-mass ratios allow for more adsorption than an equivalent mass of large particles with small surface-area-to-mass ratios do. Reduced adsorption can increase metal bioavailability by increasing concentrations of dissolved metals in associated water. The size of particles released during mining depends on mining and beneficiation methods. Finely milled ore may release much smaller particles that can both be more widely dispersed by water and wind, and which can also serve as sites of enhanced adsorption. Consequently, mine tailings released into fine-grained sediment such as silty clays found in many playas can have much lower environmental impact than those released into sand or coarse-grained sediment with lower surface area and adsorption.

Temperature exerts an important effect on metal speciation, because most chemical reaction rates are highly sensitive to temperature changes (Elder, 1989). An increase of 10 ºC can double biochemical reaction rates, which are often the driving force in earth surface conditions for reactions that are kinetically slow, and enhance the tendency of a system to reach equilibrium. Temperature may also affect quantities of metal uptake by an organism, because biological process rates typically double with every 10 ºC temperature increment (Luoma, 1983; Prosi, 1989). Because increased temperature may affect both metal influx and efflux rates, net bioaccumulation may or may not increase (Luoma, 1983).

In recent organic carbon-rich sediments, trapped interstitial fluids can commonly form a strongly reducing (anoxic) environment. Low redox potential in this environment can promote sulfate reduction and sulfide mineral deposition.

During diagenesis, much of the non-silicate-bound fraction of potentially toxic metals such as arsenic, cadmium, copper, mercury, lead, and zinc, can be co-precipitated with pyrite, form insoluble sulfides, and become unavailable to biota (Morse, 1994). Seasonal variation in flow rates or storms that induce an influx of oxygenated (sea) water can result in rapid reaction of this anoxic sediment and thereby release significant proportions of these metals. Pyritization and (or) de-pyritization of trace metals probably can be an important process in controlling bioavailability of many trace metals, especially in the marine environment (Morse, 1994).

2.3.2 Determination of bioavailability by selective chemical extraction

The extent of bioavailability is largely controlled by elemental speciation or chemical sitting in soil, which determines solubility. A number of soil testing methods and partial or sequential chemical extraction techniques and methods are used to determine element behavior (Chao, 1984; Gunn and others, 1988). Some of the chemical extractions are as follows:

1) Water or MgCl at neutral or ambient soil pH for easily soluble metals.
2) Solubility in weak base (pH 9) for humic materials.
3) A weak acid or diluted acid in a buffer solution (pH 2 to 5) to release metals associated with 14 carbonate phases.
4) A chelating (or complexing) agent such as ethylenediaminetetraacetic acid (EDTA) (Borggaard, 1976) or diethyenetriaminepentaacetic acid (DPTA) buffered to a pH of 7 (Crock and Severson, 1980).
5) Hydroxylamine hydrochloride for the "reducible" fraction associated with iron and manganese oxides/hydroxides
6) A strong acid (HCl, pH 1) to identify maximum mobility of most metals (Leventhal and Taylor, 1990)
7) Oxidation by hydrogen peroxide to release metals associated with organic matter and (or) sulfide minerals
8) A strong oxidizing acid (HNO) to execute steps (6) and (7) simultaneously

9) A mixture of a strong acid and HF to dissolve residual silicate minerals.

The choice of extractants and the order in which they are used depends on the sediment/soil type, environmental conditions, and metals of interest.

However, these sequential/partial extractions are all "operational", that is they are not completely specific to metals or chemical phases. Therefore any determination of bioavailability should be carefully calibrated, by direct measurement, with the actual behavior of metals in the soil and plants. For example, O'Connor (1988) cautions about the use of the DPTA method and shows that it sometimes gives results comparable to plant uptake and sometimes it does not. As a consequence, he recommends the direct analysis of the total plant and (or) its component parts in addition to chemical leaches in order to determine bioavailability.

2.4 Uptake of metal compounds on plants

2.4.1 Metal uptake from the soil

Uptaken metals from soil by plants through their roots to their above-ground parts or under-ground storage organs depends on

1) The total metal amount present in the soils
2) The proportion of the total that is accessible to the plants roots
3) The ability of the plants to transfer the metal across the soil-root interface.

These factors are not independent, but interact, for example, when the uptake affects plants growth because a deficient or toxic level of a metal exists. Such interactions are not deficient or toxic level of a metal exists. Such interactions are not discussed in this chapter, but must be kept in mind when evaluating plant uptake in the course of environmental studies.

The total amount of a metal in the soil is derived in the first place from natural sources, but may be increased substantially by human's industrial and agriculture activities (Berrow and Burridge, 1979). The accessibility of an element to plants in any given soil is determined by its chemical form and its location within soil. The most readily available elements are those present in the so-called soil solution in the ionic state or as soluble organic matter complexes; the least available are those firmly bound within the structure of solids, for instance, within the crystal lattice of primary rock minerals. Between these extremes the most important pool of available materials is associated with charged sites on the surfaces of very small particles such as clay and silt, and on organic matter, which together comprise what may be termed the "exchange-complex". These sites are characterized by their ability to release one ion in exchange for another, for example, calcium may exchange with magnesium, potassium or hydrogen. Such conditions as acidity, organic matter content and drainage status are among the many factors that affect the chemical forms of metals and thus their availability to plants (Mitchell, 1964).

The soil-root interface is not a passive, inert sieve. The root surface is an active boundary with characteristics varying with plant species and dependent on the particular element. The cation exchange capacity, for instance, is a property of roots that can be reproducibly measured (Crooke, 1964) and which is generally greater for dicots than for monocots. Moreover, the soil environment immediately adjacent to the roots can be strongly influenced by root exudates (Linehan et al., 1985; Merckx et al., 1986a,b), and apart from biochemical processes of transfer across cell walls within the roots, chemical process of dissolution, chelation and precipitation outside the root also occur. Microbial activity in the rhizosphere is an additional factor that must be taken into account. Elements can accumulate on plant roots, for example, Al, Cu, and Fe, sometimes without any measurable transfer to the above-ground tissues even when poor growth occur.

2.4.2 Effects of soil pH, drainage status, and organic matter to a plant metal uptake

The influence of these soil factors on the uptake of trace elements by plants has been demonstrated by many researchers. Similar general effects have been reported throughout the world, but detailed variations arise from geological, climatic, agricultural, and cropping differences.

Soil reaction (pH) has a major effect on the uptake of many elements; some become more available to plants as pH decrease (e.g., Co, Mn, and Ni), others as pH increases (e.g., Mo and Se), and some tend to be only slightly affected by pH (e.g., Cu) (Berrow and Burridge, 1979).

Effects of the organic matter content of a soil on plant uptake are complex and often indirect. Important inter-related soil characteristics that can be altered when organic matter such as farmyard manure or sewage sludge is regularly added to soil are as follow:

- The water-holding capacity
- Microbial activity, which is also strongly influenced by the quality of the organic matter, as measured by its C:N ratio
- The cation and anion exchange capacity
- The ability to supply chelating ligands

Poor drainage also favors the accumulation of organic matter in the surface horizons of the soil profile.

The relative significances of the soil factors pH, drainage status, and organic matter for the plant's uptake of particular metals depends on the root-accessible fraction form which is most likely to occur in the soil. Cation exchange processes are more important than organics chelation for Mn, while the opposite holds true for Cu (Berrow and Mitchell, 1980)

2.4.3 Essential and/or toxic metals

According to Bowen (1979), a number of elements such as As(III), as well as Al, B, Be, Cd, Co, Cr(VI), Cu, I, Mo, Ni, Se(IV), and Ti can be harmful to crops, even at quite low concentration. Nevertheless, many of these elements are also essential for good growth. Mechanisms of toxicity may operate by altering the permeability of cell memebranes by forming antimetabolites, by reacting with essential metabolites, or by substituting in part for other essential ions.

The forms available to plants of many of trace elements (e.g., Ag, Au, Be, Bi, Pt-metal, Sb, Sn, Te Ti, Tl, and Zr) are present at such low levels in uncontaminated soils in are so low that the absence of suitable analytical techniques has limited studies of soil-plant relationships. Their behavior can only be anticipated, in a general way, by comparison with the most chemically similar elements that have been more intensively studied. Caution must be exercised in making such comparisons, however, because the elements that have received most study are naturally those having a biological function. This must be kept in mind when comparing, for instance, the behavior of Cd with Zn or of Ag with Cu. A summary of current information on essentiality and toxicity is given in Table 2.5.

Table 2.5 A summary of current information on the essentiality and toxicity of metals (Berrow and Burridge, 1979)

Elements	E_p	E_a	T_p	T_a[a]	**Elements**	E_p	E_a	T_p	T_a[a]
Aluminum			/		Manganese	/	/	/	/
Antimony					Mercury			/	/
Arsenic			/	/	Molybdenum	/	/	/	/
Beryllium			/	/	Nickel		/	/	
Bismuth					Niobium				
Cadmium			/	/	Pt-metals			/	
Chromium		/			Selenium		/	/	/
Cobalt		/			Silver			/	
Copper	/	/	/	/	Tantalum				
Gallium				/	Tellurium				
Germanium					Thallium			/	/
Gold					Tin		/		/
Indium				/	Titanium				
Iron	/	/			Tungsten			/	/
Lanthanum					Uranium				/
Lead			/	/	Vanadium	/	/	/	/
Lithium				/	Zinc	/	/	/	/
Magnesium	/	/			Zirconium				/

[a] E_p essential to plants, E_a essential to animals, T_p toxic to plants, T_a toxic to animals

2.5 Literature reviews

Ogunwande *et al.* (2008) studied the effects of the carbon to nitrogen ratio and the turning frequency on composting chicken litter in turned-windrow piles. The raw chicken manure was co-composted with sawdust in turned-windrow piles. The experimental set up was a 3 × 2 factorial design with C:N ratios at 20:1, 25:1 and 30:1, and with turning frequencies at every 2 days and every 6 days. Six piles of chicken litter were built in pits with a size 1.2 m × 1.2 m square base and a height of 0.3 m. During composting, the moisture content of the piles was periodically replenished to 55%. The results showed that the C:N ratio had a significant ($p \leq 0.05$) effect on the pile temperature, total nitrogen (TN), total carbon (TC), C:N ratio, dry matter(DM), total phosphorus (P) and total potassium (K), while the turning frequency had a significant ($p \leq 0.05$) effect on the pile temperature, pH, TC, C:N ratio and total K. A significant part of the TN losses was attributed to NH3 volatilization while that of the TC losses were attributed to organic matter degradation. It was observed that moisture loss increased as the C:N ratio and turning frequency increased. All treatments reached stability at about 87 days as indicated by the decline of pile temperatures to values close to the ambient temperature.

Borazjani *et al.*, (1997, 2000) studied the use of high nitrogen feedstock include poultry manure, cow manure, horse manure, gin trash and inorganic fertilizer to amend high carbon containing wood wastes. The finding study suggested the optimum C/N ratios are between 15:1 and 30:1 and the optimum moisture content is 50%. The study concluded that the composting process may be enhanced by amending the high carbon containing wood waste with high nitrogen feedstock. The best results in terms of reductions in toxicity, weight loss and color change were obtained with a poultry manure amended treatment.

Barker and Bryson (2002) have revealed the bioremediation of heavy metals and organic toxicants by composting and concluded that the presence of metabolizable carbon in compostable feedstock enhances the microbial diversity and activity during composting and promotes the degradation of pesticides, PAHs and

PCBs. Also, metallic pollutants can be converted into less bioavailable organic species. The overall conclusion drawn from the study is that the composting process may be a promising way to degrade or bind pollutants to innocuous compounds.

Liu *et al.,*(2007) studied the evolution of heavy metal speciation in the course of the aerobic composting of sewage sludge, and investigated the influence of composting process parameters, including pH, temperature, and organic matter (OM) content, on the distribution of heavy metal speciation in composted sludge using SEA, developed by Tessier et al. Results showed that during the composting process, the contents of the residue fractions for Pb, Zn, and Cd were decreased while those for Ni and Cr were increased, and the Cu residue fraction remained almost constant. The contents of total mobile fractions for Zn and Pb significantly increased, but the increases for Cu and Ni were not so remarkable. There were significant degree of correlations between heavy metal fractions and changes of some selected parameters (for example, the pH, temperature, and OM content). Only the content of the total mobile fractions for Cu could be predicted from its total content. For the prediction of the total mobile fractions of Zn, Ni, Cd and Cr, the R^2 value was significantly increased by the inclusion of other variables such as the pH, temperature and OM content.

Nomeda S. *et al.,* (2007) investigated the variation of metal distribution (Cu, Mn, Pb, and Zn) in sewage sludge composted by using SEA. The results found that the total contents of Cu and Zn in the composted mixtures increased after the composting process. Mn and Zn were mainly found in mobile fractions. Cu and Pb were strongly associated with the stable fractions. These fives metal fractions were used to calculated the metal mobility in the sewage sludge and composted mixture. The mobility of Mn, Pb, and Zn (but not Cu) increased during the composting process. The metal mobility in the composted mixture ranked in the following order: Mn>Zn>Pb>Cu.

Rahman *et al.,* (2004) studied the uptake of As, Cu, and Cr from soil contaminated with CCA-treated wood in garden beds under realistic conditions by crops. Four replicates of carrot (*Daucus carota* var.*sativus* Hoffm. cv. Thumbelina), spinach (*Spinacia oleracea* L. cv. Indian Summer), bush bean (*Phaseolus vulgaris* L. cv. Provider), and buckwheat (*Fagopyrum esculentum* Moench cv.Common) were grown in pots containing these soils in a greenhouse. After being harvested, plant materials were dried, ground, digested, and analyzed for As by inductively coupled plasma-hydride generation (ICP–HG). Concentrations of As in all crops grown in contaminated soils were higher than those from the control soils. The levels of As in the crops remained well below the recommended limit for As set by the United States Public Health Service (2.6 mg/kg fresh wt.).

McMahon *et al.,* (2008) The objective of the present study have evaluated the viability of reducing landfill requirements to satisfy EC Landfill Directive requirements by applying composting/bioremediation techniques to the construction and demolition (C&D) industry waste stream at laboratory scale. The experimental study was carried out in nine test rigs to examine different wood mixtures; untreated timber, creosote treated timber and chromated copper arsenate (CCA) treated timber. Several experimental variables affecting the process were characterised and optimised. These include the best nitrogen additive and optimum moisture content required for composting. Poultry manure was found to be the best nitrogen additive. The optimum moisture content was decreased after the addition of poultry manure. The composting/bioremediation process was evaluated through monitoring the microbial activity, carbon dioxide emissions and toxicity examination of the composted product. A typical temperature profile suggested that untreated and CCA treated mix could be classified as hot composting whereas creosote treated mix could be classified as cold composting.

CHAPTER III

METHODOLOGY

The experiments were conducted in two phases, the aerobic composting process and metal plant uptake tests. The details of the experiments are described in this chapter.

3.1 Aerobic composting process phase

3.1.1 Composting materials

Wood shaving

Wood shaving of new mixed untreated wood was taken from a wood factory located in Amphoe Mae Rim, Chiang Mai Province. CCA-treated wood shavings were prepared by manually shaving mixed CCA-treated wood waste purchased from the above mentioned wood factory, using a planer and homogenized by manual mixing before analysis and composting.

Nitrogen supplement

To balance the C/N ratio in the composting process, chicken manure was added. The chicken manure was obtained from the Department of Animal Science under the Faculty of Agriculture of Chiang Mai University, Chiang Mai. Before analysis and composting, the chicken manure was homogenized by manual mixing.

Microbial supplement

Microbial supplements are used to provide additional microorganisms for the composting system. The microbial supplement used in this study contained the mature compost from household organic waste composting. Fig.3.1 shows all mentioned materials used in the composting process.

Table 3.1 Properties of the household organic waste compost

Properties	Value
C/N	19.22
pH	7.86
CEC (Cmol/kg)	61.4
GI (%)	132.72
Moisture content (%)	62.51
N:P:K (%N, %P_2O_5, %K_2O)	1.50 : 0.52 : 1.84
Size smaller than 12.5 mm (%)	46.68

Sawdust from untreated wood

Wood shaving from CCA-treated wood

Chicken manure

Mature compost

Figure 3.1 Composting materials

3.1.2 Composting procedure

Four composting units were prepared at the Department of Environmental Engineering, Chiang Mai University, as shown in Figure 3.2. Four composting piles were set up using four mixtures as shown in Table 3.2

Figure 3.2 Composting units

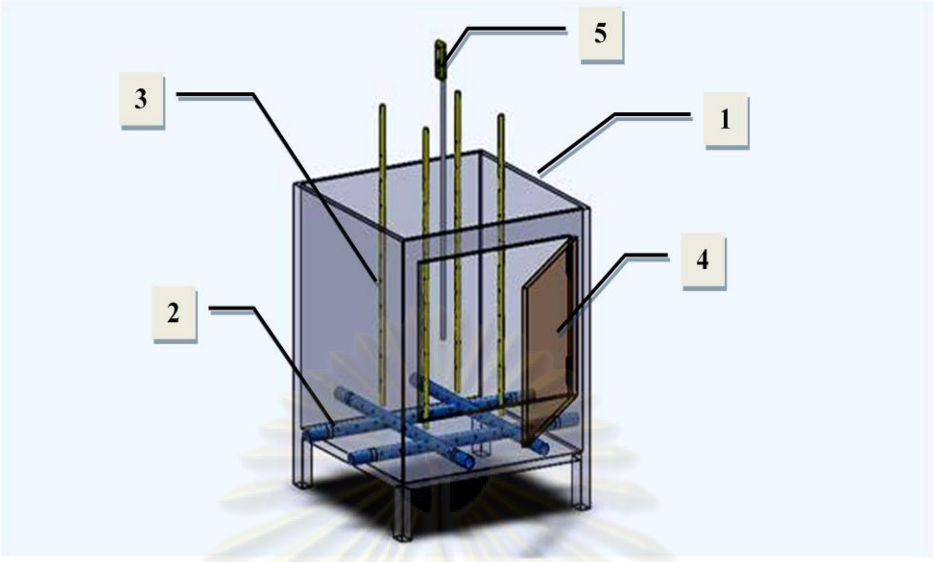


Figure 3.3 Composting unit details

Description of Figure 3.2

Point No.	Materials	Description
1	Wood box (1x1x1 m^3)	Composting unit
2	Perforated PVC pipe (Dia. 5 cm.)	Horizontal air-vent-pipe (Figure 3.3)
3	Perforated PVC pipe (Dia. 2.5 cm.)	Vertical air-vent-pipe (Figure 3.4)
4	Wood plate (0.80x0.65 m^2)	Gate
5	Digital thermometer	Model ST-1

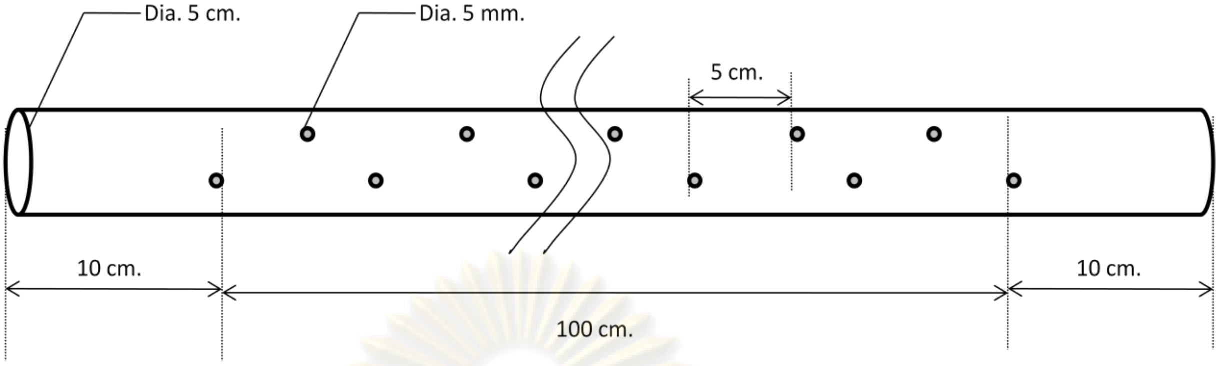


Figure 3.4 Horizontal air-vent-pipe

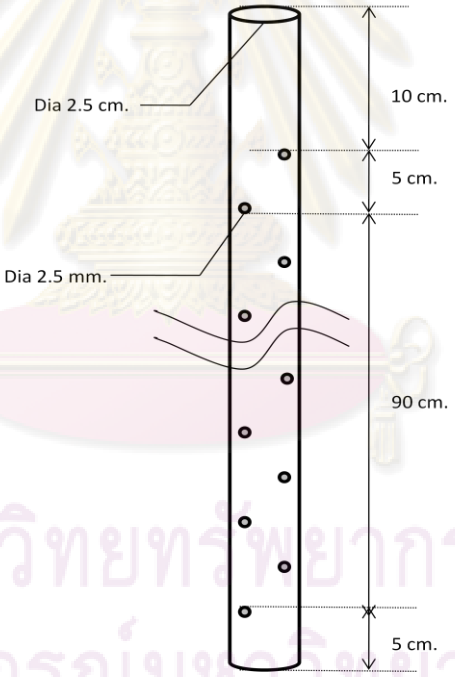


Figure 3.5 Vertical air-vent-pipe

Table 3.2 The quantity of each composting materials in each compost pile

Materials	Quantities, kg (%wet weight) (except C/N)			
	Pile 1	Pile 2	Pile 3	Pile 4
Wood shaving from untreated wood	102	68	33.4	-
Wood shaving from CCA-treated wood	-	29.5	59	88.5
Chicken manure	61	60.3	59.3	58.4
Mature compost	8.15	7.90	7.58	7.34
C/N	25.99	25.00	25.72	25.48

The characterizations of the raw composting materials were pre-determined. Then, the precise quantity of each material was calculated prior being placed in the composting pile to provide the optimum composting condition. The method of calculating the quantity of each composting material is presented in Appendix A.

The composting process conducted from July to December 2009. Each compost pile was equipped with a vertical and horizontal air-vent-pipe and manually turned weekly for the first month and biweekly after that to provide oxygen and to promote homogeneity of the materials. The moisture content of each pile was controlled to be in the range of 55-60% by spraying water to maintain the optimum condition for composting. Pile temperature at the central portion of each pile was measured daily using a digital thermometer (Model ST-1). Subsamples were randomly collected once a week from three equidistant cross sections and three different depths of pile: the surface (5-7 cm below the surface of the pile), middle (50-60 cm below the surface of the pile), and bottom (90-100 cm below the surface of the pile). Each sample was taken by mixing nine subsamples from the whole profile and divided into two parts, one of which was immediately kept for the determination of pH, electrical conductivity and the germination index, while the other samples were dried at 90 °C for 48 h and then, ground to reduce a size that passed through a 1 mm sieve. These samples were placed in labeled polyethylene bags that were kept in a desiccator in preparation for further chemical analyses.

3.1.3 Sample analysis

3.1.3.1 General analysis

In this study, a representative sample was taken from the homogenized compost pile for the chemical analysis presented in Table 3.3

Table 3.3 Chemical analytical methods and instruments used

Parameters	Analytical methods	Analytical instruments
pH*	AOAC 973.04	Horiba pH meter F-21
Conductivity*	BS EN 13038	Cond 330i WTW 82362 Weiihelm
Moisture content	Oven drying method**	WTC binder 7200 TUTTLINGEN/GERMANY
Total nitrogen	Macro-Kjeldahl distillation** method	- Digestion system 6 1007 Digester. - FOSS 2100 Kjeltec distillation Unit.
Total organic carbon	Walkley and Black Method**	-
Total volatile solids	USEPA, 2001 method 1684	CARBOLITE CWF 1200
Total heavy metals (Cu, Cr, As)	Cu and Cr : $HCl-HNO_3$ digestion method** As : $HCl-H_2SO_4-HClO_4$ digestion method**	Atomic Absorption Spectrophotometer (AAS) (Model GBC Avanta Model HG3000).

* The pH and conductivity were determined by measuring of a slurry of 1:10 ratios of material or compost to water.

** Thai Agriculture Standard TAS 9503-2005

3.1.3.2 Sequential extraction of composting

The method of sequential extraction used in this study was developed by Tessier et al. (1979), and it has been widely applied in various composting studies (Luo and Christie, 1998; Ciba et al., 2003; Zheljazkov and Warman, 2003). Each of the chemical fractions of Cu, Cr, and As in the compost was operationally defined as follows:

(1) Water soluble fraction: 1 g. (dry wt.) of compost was extracted by 15 ml of deionized water, and shaken at 220 rpm for 2 h at room temperature.

(2) Exchangeable fraction: The residue from (1) was extracted by 8 ml of 1.0 M $MgCl_2$ (pH7) and shaken at 220 rpm for 1 h at room temperature.

(3) Carbonate-bound fraction: The residue from (2) was extracted by 8 ml of 1.0 M NaOAc (pH5) and shaken at 220 rpm for 5 h at room temperature.

(4) Fe/Mn oxide-bound fraction: The residue from (3) was extracted by 0.04 M NH_2OHHCl in 25% acetic acid (v/v) for 6 h at $96\pm3\ ^{\circ}C$ with occasional agitation.

(5) Organic fraction bound metals: The residue from (4) was extracted with 2 ml of 0.02 M HNO_3 and 5 ml of pH 2, 30% H_2O_2 for 2 h at $85 \pm 3\ ^{\circ}C$ with occasional agitation, an additional 3 ml of pH 2, 30% H_2O_2 for 3 h at $85 \pm 3\ ^{\circ}C$ with occasional agitation. After cooling, 5 ml of 3.2 M NH_4OAC in 20% HNO_3 (v/v) is added and agitated continuously for 30 min at room temperature.

(6) Residual fraction: the residue from (5) is digested with HNO_3-HCl

The extractions were conducted in 50 ml centrifuge tubes. Between each extraction step, separation was accomplished by centrifugation at 5,000 rpm for 30 min. After that the supernatant was filtered through Whatman Grade no.5 filter paper and then diluted to 50 ml with 1% HNO_3 (v/v). The extracted solution was stored at 4 °C in a polyethylene bottle for trace metal analysis. The residue from each extraction step was washed using 8 ml of deionized water and then shaken at room temperature for 15 min. Then after centrifugation at 5,000 rpm for 15 min, the supernatant was discharged and the remaining residue was kept for the next extraction step. The heavy metal concentration was determined by using an atomic absorption spectrophotometer (AAS) (Model GBC Avanta Model HG3000).

3.1.3.3 Germination Index

The effect of compost maturity on seed germination and germination index were determined using *Brassica campertris var. chinensis* seeds, in accordance with the Thai Agriculture Standard TAS 9503-2005 method. The extraction solutions of composts prepared by shaking 10 g samples with 100 mL deionized water in a volumetric flask for 1 h, using a horizontal shaker set at about 180 times per minute. After shaking, the suspension was filtered with filter paper. Four sterilized germination plates containing ten seeds each placed on filter paper were prepared. Each compost solution (3 ml) was added into the germination plate and deionized water was used as a control. The germination plates were incubated in a darkroom at the temperature of 28 °C to 30 °C for 48 hours. After 48 hours of incubation, the lengths of the roots were measured. The percentage of germination index of plant seeds were calculated by using the following formula.

$$\text{Germination Index (\%)} \\ = \frac{\text{\% of germination in compost solution x root length in compost solution x 100}}{\text{\% of germination in distilled water x root length in distilled water}} \qquad (1)$$

3.2 Metal plant uptake testing phase

3.2.1 Raw materials

Compost

The composts used in this test were the mature composts air-dried for 30 days at room temperature from the four composting piles in Phase 3.1. These composts were homogenized by manual mixing with soil for growing plant.

Seeds

Brassica campertris var. chinensis seeds were used which were purchased from Chia Tai Company, Bangkok, Thailand. These seeds were soaked in deionized water over-night prior to their use.

Soils

Soils used were collected from the Sameung royal project area. These soils were air dried for 15 days at room temperature and homogenized by manual mixing before being mixed with the composts.

CCA treated wood

CCA-treated wood shavings were prepared by manually sawing the mixed CCA treated wood wastes purchased from the wood factory which was mentioned in Phase 3.1 above, using a planer and homogenized by manual mixing before being analyzed and used in planting.

Soil CCA treated wood shaving Compost from pile1

Compost from pile 2 Compost from pile 3 Compost from pile 4

Seeds

Figure 3.6 Planting materials

3.2.2 Planting procedure

Six groups of pot tests were prepared at the Department of Environmental Engineering, Chiang Mai University (see Figure 3.7). Soil and compost from each pile were manually mixed before being used in planting with the ratio of soil and compost at 1:2 v/v. The soil was sieved through an 8-mm sieve to remove rocks, large roots, and debris. Approximately 1.1 kg of soil and 1 kg of compost were used for each pot containing 3 seeds of *Brassica campertris var. chinensis* seeds. The pot used had 20 cm in diameter and 20 cm height. The experimental design was completely randomized with eight replicates of each group. The plants were grown for 45 days and watered daily and rotated periodically. About 200-300 ml of water was sprayed per pot depend on the soil condition in the morning and afternoon. No fertilizer was add during the planting period. The plants were harvested at 15, 30 and 45 days after planting. During the planting process, the planting area was covered by net to protect the plant from insects and other inhibitory elements from outside.

Figure 3.7 Pot tests

3.2.3 Sampling and analysis procedure

After harvesting, plants were washed thoroughly to remove adhering soil particles using tap water followed by two rinses in deionized water. The length and weight of the fresh roots, trunks, and leafs were measured for determining the top and root growth. The plant materials were weighed to determined fresh weight and then dried in 60 °C for 48 h, after which time they were reweighed to determine their moisture content and total dry matter production. After that, the dried plants were ground to pass through a 1 mm sieve. These samples were kept in labeled polyethylene bags in a desiccator. Sequential extraction analysis (SEA) was used to investigate the geochemical partitioning of arsenic, copper, and chromium in pure soil, soil mixed with compost and the uptake parts of plant (the roots, leaves and trunk) during the growth process. The heavy metal analysis was duplicated. The concentration of arsenic, copper, and chromium from each SEA fractions were analyzed using Atomic Absorption Spectroscope (AAS).

The sampling and analysis procedures are shown in Table 3.4, and an overview of the metal plant uptake tests procedure is shown in Figure 3.8.

Table 3.4 Sampling and analysis procedure

Testing process	**Sample**	**Analysis**	**Sampling frequency**	**Sampling procedure**
Preparation of raw material.	Soils	- Total concentration of Cu, Cr, and As. - SEA of Cu, Cr, and As.	Once before planting.	Samples were prepared by taking of subsamples from 10 different points of the soil heap (bottom, surface side, and centre)
	Soils + Composts	- Total concentration of Cu, Cr, and As. SEA of Cu, Cr, and As.	Once before planting.	Samples were prepared by taking of subsamples from 10 different points of the soils and composts mixture heap (bottom, surface side, and centre)

Table 3.4 Sampling and analysis procedure (continued)

Testing process	**Sample**	**Analysis**	**Sampling frequency**	**Sampling procedure**
Preparation of raw material. (Continued)	CCA treated wood	- Total concentration of Cu, Cr, and As. - SEA of Cu, Cr, and As..	Once before planting.	Samples were prepared by taking of subsamples from 10 different points of the CCA treated wood shaving heap (bottom, surface side, and centre)
Planting process	Soils, Soils+ Composts And Pure CCA treated wood	- Total concentration of Cu, Cr, and As. -SEA of Cu, Cr, and As.	Every 15 days after planting started.	Samples were prepared by taking of subsamples from 10 different points of the soils and composts mixture in each pot (bottom, surface side , and centre)
Planting process	Plants	- Total concentration of Cu, Cr, and As. - SEA of Cu, Cr, and As. - Top and root growth (measurement of the length and weight of fresh roots, trunks and leafs.)	Every 15 days after planting started.	Samples were taken directly from the plants.

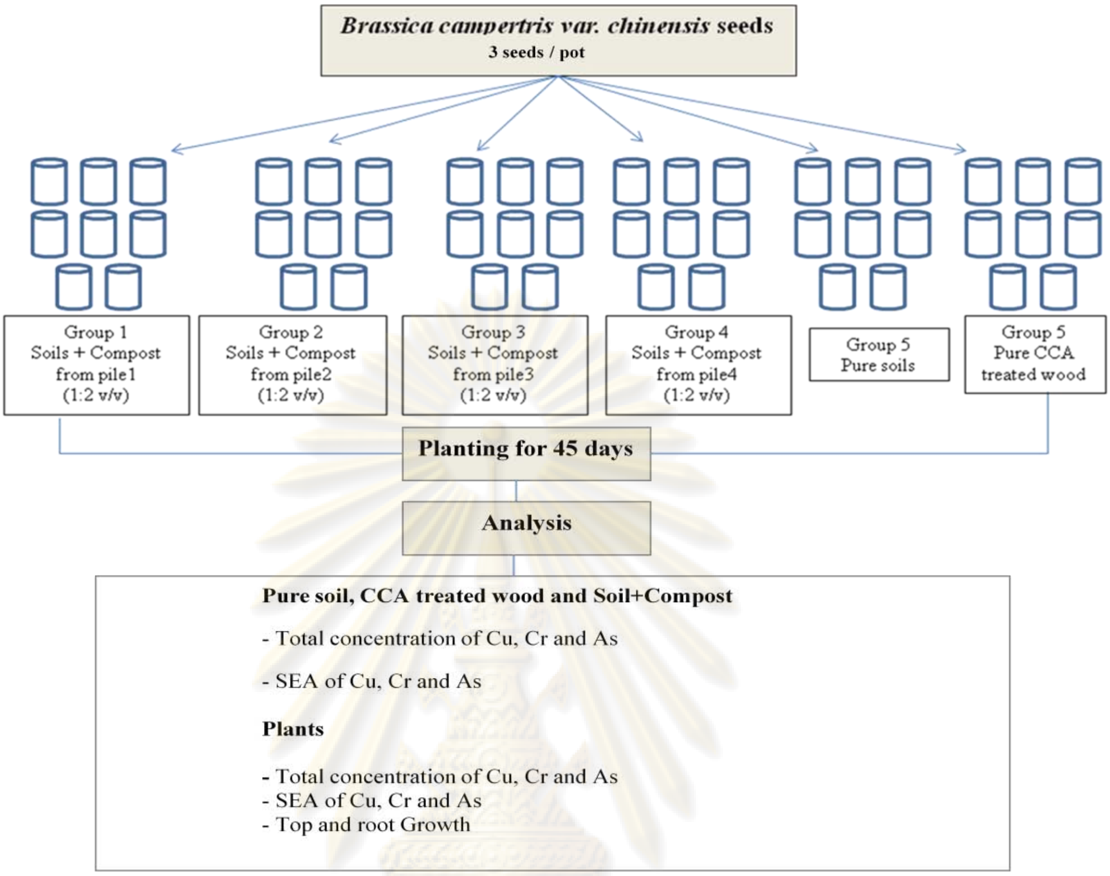


Figure 3.8 An overview of the metal plant uptake test procedure

3.2.4 Statistical analyses

The pH, electrical conductivity, total carbon and total nitrogen results in this experimental are expressed as 95% RSD of five replicate samples, while the data of germination index are the means of four replicates. The data of heavy metals concentration and total volatile solids are reported as mean of duplicate samples.

For pot tests, each individual pot was considered as an experimental unit. The data of heavy metal concentrations were reported as mean of duplicate samples.

A One-way ANOVA at 95% confidence level was selected to compare the results between the groups of samples using using MINITAB release 14.12.0 statistical software (2004).

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Characterization of composting

4.1.1 Characterization of composting materials

4.1.1.1 Raw composting properties

As mentioned in Chapter III, the raw composting materials used in this study consisted of untreated wood shaving, wood shaving from CCA-treated wood, chicken manure and the mature compost from the household organic waste composting. The characterization of these materials is different. While the diversity of compost feedstock material makes an estimation of control parameters somewhat difficult, a precise number need to be determined. The characterizations and quantities of raw composting materials used are shown in Table 4.1.

Table 4.1 Characterization of raw composting materials

Composting materials	pH	Conductivity (mS/cm)	C (% dry wt.)	N (% dry wt.)	C:N ratio	Moisture content (%)
Wood shaving from untreated wood	7.81	1.52	62.24	0.46	135	30.83
Wood shaving from CCA-treated wood	7.62	1.73	59.77	0.21	280	29.11
Chicken manure	5.27	4.20	26.34	4.18	6.30	25.44
Mature compost	7.87	-	24.05	1.25	19.2	62.51

4.1.1.2 Feature of compost during composting process

During composting process, the feature of compost from four compost piles changed with time. At the starting of process, the compost mixture was brown in color, generated unpleasantly odor, present unhomogeniously in texture, and generated high vapor while turning. After composting for 2 months, the unpleasant odor was diminished and became to earthy odor. The compost color was quite dark brown and generated lesser vapor when turning. Finally, after the whole 140 days of composting, the feature of finished compost in four compost piles changed to be black color, and had a pleasant, earthy odor. The particles were relatively uniform and soil-like in texture. Figure 4.1 presents the started compost mixture and finished compost from four compost piles.

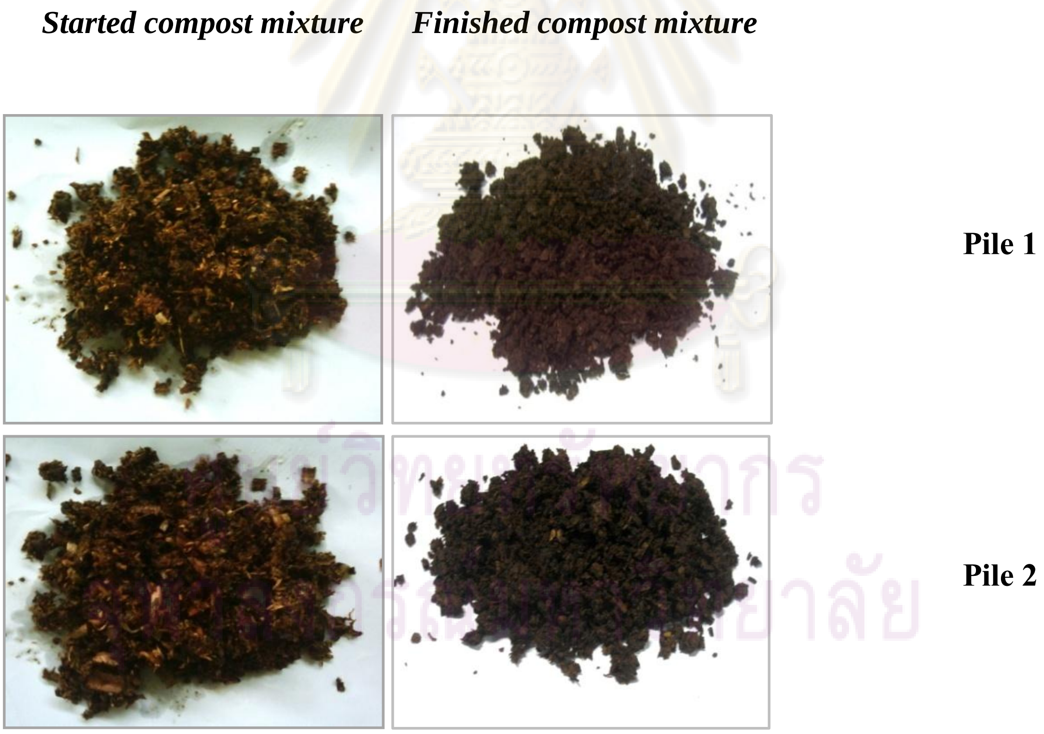


Figure 4.1 Started and finished compost mixture from four compost piles

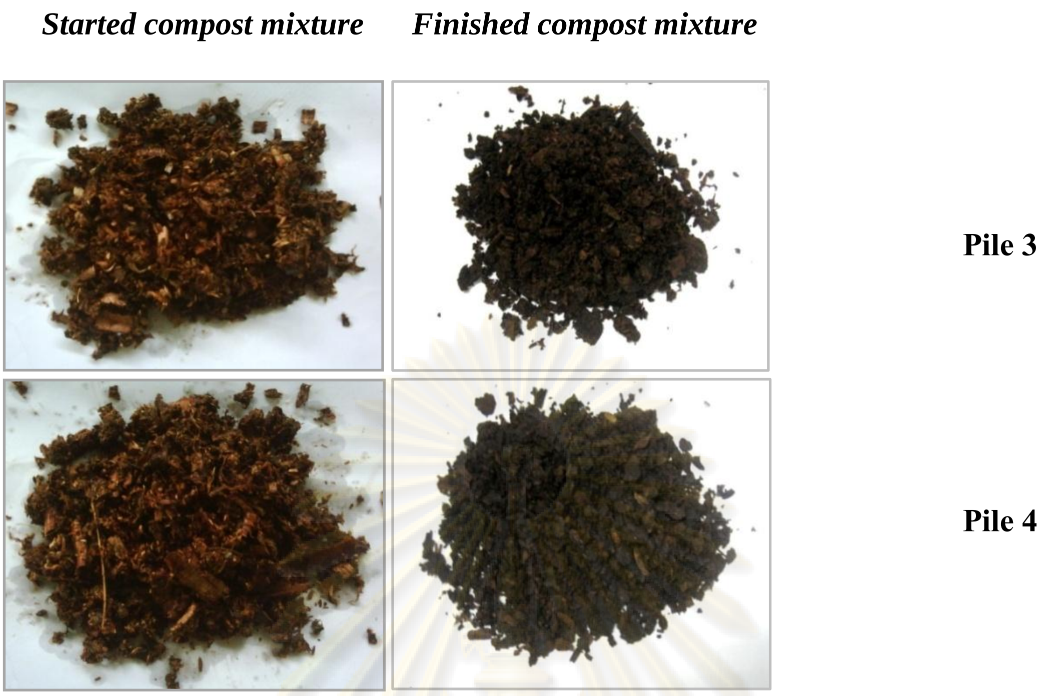


Figure 4.1 Started and finished compost mixture from four compost piles

4.1.2 Temperature

During the composting process of four compost piles, the temperature at the central portion of each pile was measured daily using a digital thermometer. The results of the temperature of all piles variations are presented in Appendix B and Figure 4.2.

Temperature at the central portion of compost pile 1 started with 28ºC at the first day of composting. The composting temperature sharply increased at the initial phase and reached the highest value of 59.9 ºC after composting for 3 days, and then decreased to the room temperature around 20 ºC after the composting process proceeded for 148 days. The thermophilic and mesophilic phase of composting lasted for 40 and 95 days, and their average temperatures were 50.4 ºC and 32.9 ºC, respectively.

Temperature at the central portion of compost pile 2 started with 29ºC at the first day of composting. The composting temperature sharply increased at the initial phase and reached the highest value of 60.1 ºC after composting for 3 days, and then decreased to the room temperature after the composting process proceeded for 147 days. The thermophilic and mesophilic phase of composting lasted for 38 and 97 days, and their average temperatures were 48.3ºC and 27.3 ºC, respectively.

Temperature at the central portion of compost pile 3 started with 29ºC at the first day of composting. The composting temperature sharply increased at the initial phase and reached the highest value of 59.7 ºC after composting for 3 days, and then was decreased to the room temperature after the composting process proceeded for 140 days. The thermophilic and mesophilic phase of composting lasted for 36 and 96 days, and their average temperatures were 50.3ºC and 28.9 ºC, respectively.

Temperature at the central portion of compost pile 4 started with 30ºC at the first day of composting. The composting temperature sharply increased at the initial phase and reached the highest value of 60 ºC after composting for 3 days, and then decreased to the room temperature after the composting process proceeded for 139 days. The thermophilic and mesophilic phase of composting lasted for 29 and 103 days, and their average temperatures were 50.6ºC and 27.6 ºC, respectively.

The results of one-way ANOVA test (see appendix C) shows that the mean temperatures of four piles were not significantly ($p > 0.05$) different.

It was found in this study that the temperatures of four compost piles were observed as three phases:

a) The thermophilic phase lasted until approximately 29th -40th day, during which the temperature were in the range of 45ºC-60ºC. The maximum temperature of four compost pile reached after three days of composting, the highest value was observed in pile 2. The average temperature in the thermophilic phase of four piles shows the similarity results. In addition, the longest thermophilic period was occurred in compost pile 1.

b) The mesophilic phase, in which the temperature decreased from approximate 45ºC to 25ºC during approximately 95th -103th day of composting. This phase lasted longer than the thermophilic phase. The maximum average temperature of four compost piles during this phase was found in pile 1. The pile 4 was the first one that its temperature decreased to mesophilics phase and lasted in this phase longer than other piles.

c) The stable phase, which compost piles' temperature reached the room temperature and indicated no measurable changes ($p > 0.05$). The composting process of four piles reached the room temperature within 148th, 147th, 140th and 139th days of composting, respectively.

The temperature variation during the composting process of four piles followed a typical pattern exhibited by many researchers (Tiquia *et al.,*1998; Nomeda S. *et al.,*2007; Ogunwande *et al.,* 2008). There were increases in pile temperatures immediately after each turning operation in the early days of the experiment. This was responsible for the rise and fall pattern of the temperature profile (see Fig.4.2) which had been reported as the re-activation of the composting process by the incorporation of external material into the pile (Gracia-Gomez *et al.*, 2003). Typically, the compost temperatures are regulated through aeration and turning. Both methods allow air to pass over the surface of or through the composting substrate thus lowering the temperature by enhancing the vaporization of moisture. Aerating and turning also delivers oxygen to the composting substrate, which can increase the microbial activity and accelerate the substrate stabilization rate.

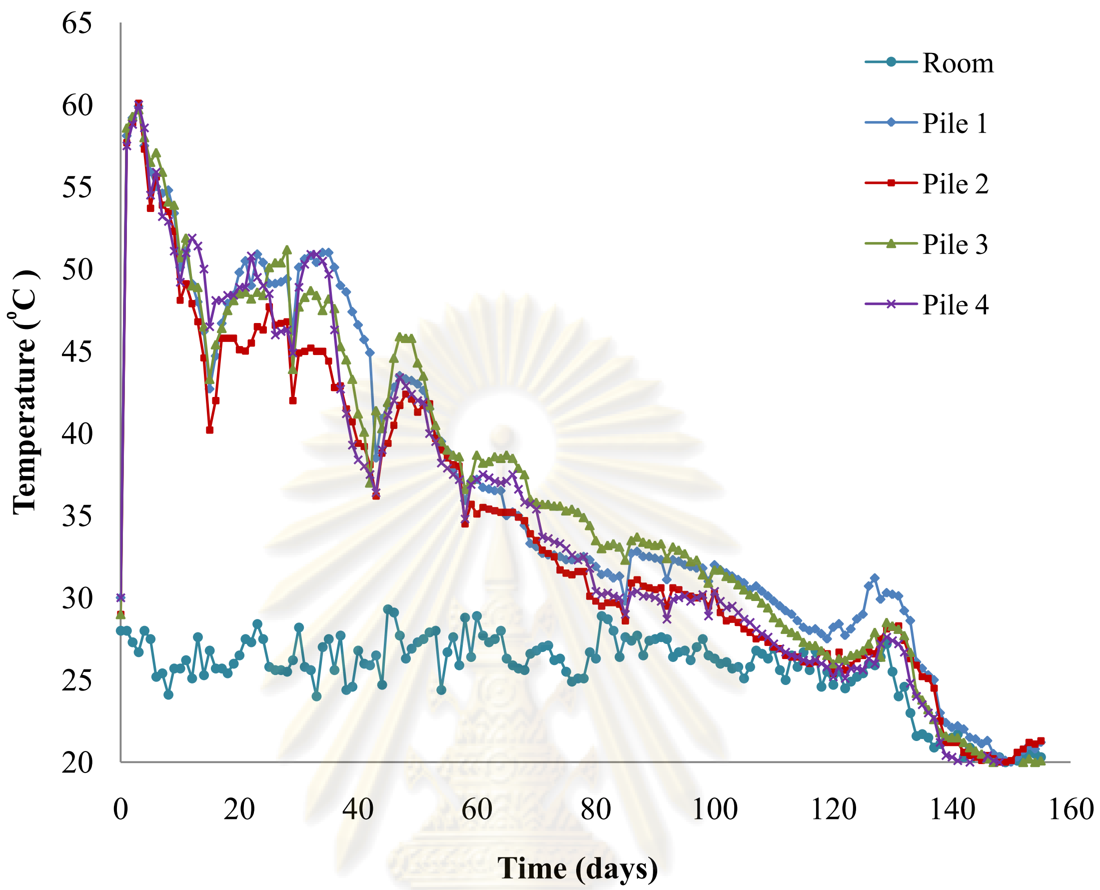


Figure 4.2 The time versus temperature variation during composting of four compost piles.

4.1.3 Moisture content

Water is the key ingredient that transports substances within the composting mass and makes the nutrients physically and chemically accessible to the microbes. Maintaining moisture content within a 40 to 60 percent range can significantly enhance the composting process (Haug, 1980). In this study, the moisture content of each pile was controlled to be in the range of 50-60% by spraying water to maintain optimum process condition for composting. The water was daily sprayed on the surface of the compost pile, the quantity of water depended on compost condition and keep away from the excessive leachate. The data of weekly moisture content of four piles are shown in Appendix B. Figure 4.3 shows the variations of moisture contents during the composting process of four compost piles.

During the composting process, the average values of moisture contents were in the range of 58.47% and 55.83%. When the mean values of the moisture content of four compost piles were compared, it was found that compost pile 1 presented the highest value (58.47%) whereas the compost pile 4 presented the lowest value (55.83%).

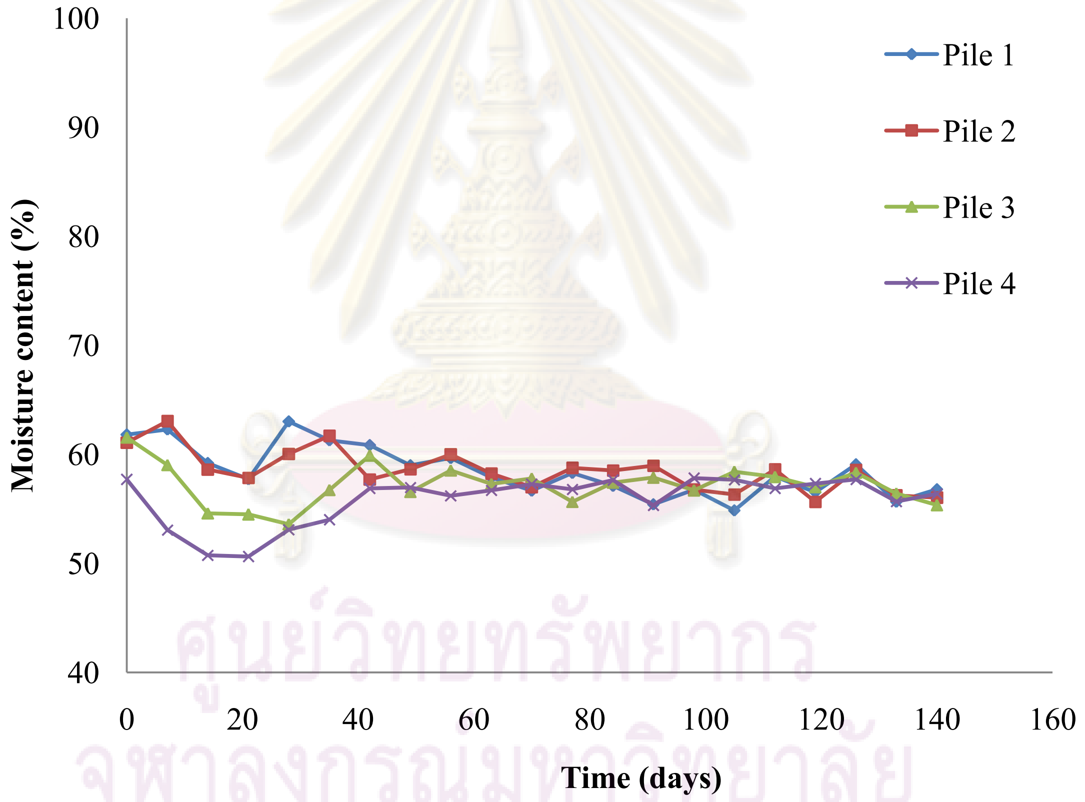


Figure 4.3 The time versus moisture content variation during composting of four compost piles.

4.1.4 pH

pH is one factor which influences the composting process, indicates the maturity of compost and also describes the role of microorganisms. The data of pH during 140 days of composting process in this study is shown in Appendix B. The time-pH variation during the composting process is presented in Figure 4.4.

Like temperatures, pH levels tend to follow a success pattern through the composting process from many studies (Tiquia *et al.*,1998; Nomeda S. *et al.*,2007; Ogunwande *et al.*, 2008).

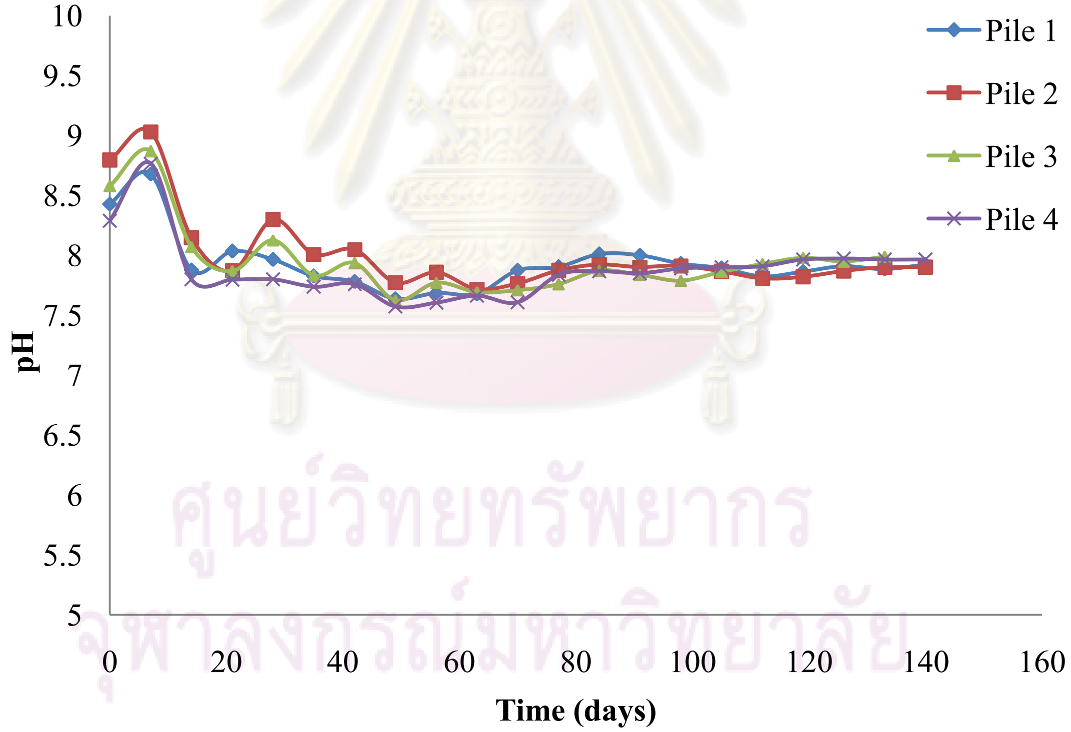


Figure 4.4 The time versus pH variation during composting of four compost piles.

As is illustrated in Figure 4.4, the initial values of pH were alkaline within the range of 7.9 and 8.7, during the first 21 days of composting. After that, they decreased to approximately 7.6-7.7 during the 49th -70th day, and then they slightly increased to remain around 7.9 to 8 until the 140th day of composting.

The pH level in this study showed that it took place in the composting decomposition phase (Gray et al., 1971b; Rynk et al., 1992). The presence of high pH at the initial was probably due to the NH_3 generated in compost piles which increased the pH to alkaline phase. Moore *et al.,* 1997 found that NH_3 volatilization from poultry litter increases once pH rises above 7.0. The reduction of the acidity values observed during the 49th -70th day in all compost piles were probably brought about by the decomposition of organic matter in the compost piles (Baeta-Hall *et al.*, 2005) due to the microbial activities in the mesophilic temperatures (25 ºC-45 ºC). The attainment of pH values of between 8.0 and 9.0 indicated that the composting process was successful and fully developed (Sundberg *et al.*, 2004). In addition, the final values of pH were an indication of stabilized organic matter (Sesay *et al.*, 1997).

The results from one-way ANOVA test indicated that average pH values of all piles were not significantly (p> 0.05) different (see Appendix C).

4.1.5 Total volatile solids

The total volatile solids (TVS) is one of important parameters which able to indicate the maturity of compost. The results of TVS during 140 days of the composting process are shown in Appendix B and Figure 4.5. The variation of TVS is manifested by a decline of volatile solids values of four compost piles and an increase in their stability

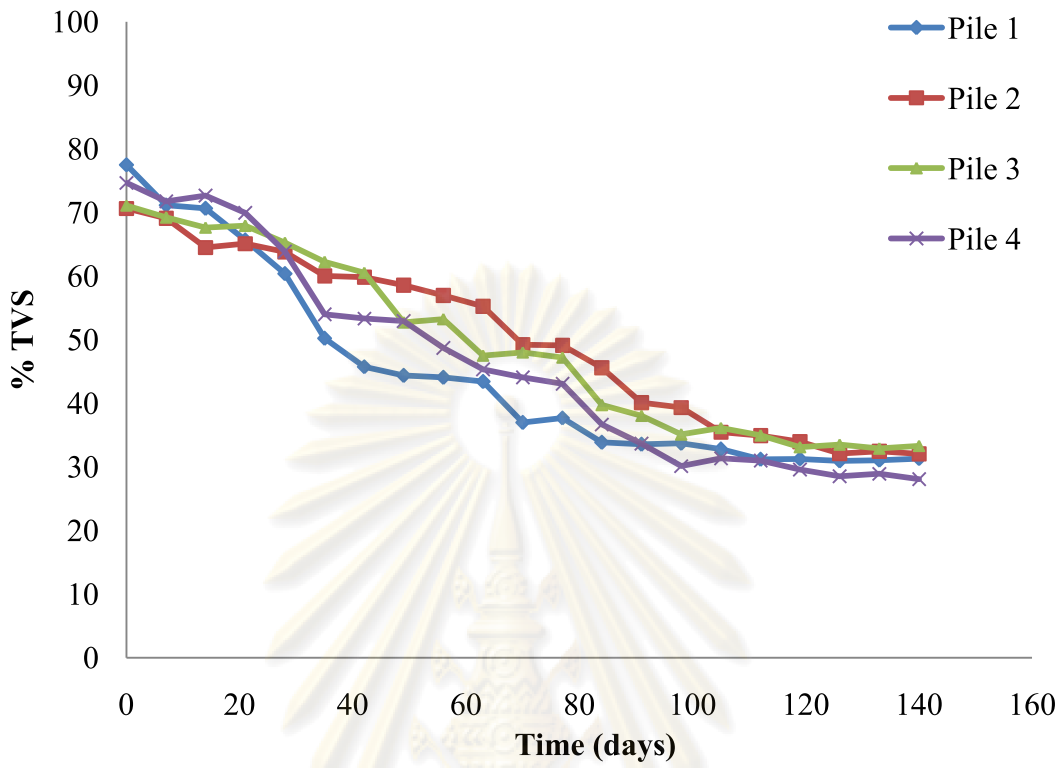


Figure 4.5 The time versus total volatile solid during composting of four compost piles.

At the beginning period of the composting process, TVS in all piles were found to be in the range of 70.6% to 77.5%. They decreased continuously to be in the range of 31.3% to 33.3% around the 105th day and after that became stable until the end of the composting period at 140th day.

Because the compost process is a biological decomposition, oxidation of the carbon in organic matter is converted to carbon dioxide is an important activity. This decomposition reduces the complex substance to the simpler form and becomes the biodegradable forms. Molecules that either is not only partly or completely unbiodegradable tend to remain unchanged. Therefore, the trend of percentage of TVS is decreasing during the composting process. While a part of the decompostable mass lost, the stability is toward increased.

From the statistical analysis using one-way ANOVA test, it indicated that the average values of TVS during composting process of four piles were not significantly (*p*> 0.05) different (see Appendix C).

4.1.6 Total organic carbon content

The organic carbon content of compost depends largely on the organic characteristics of the feed substrate. In this study, the woody materials were mostly consisted in compost mixture, which providing high carbon content. However, the carbon compounds in woody materials are largely bound by lignin which is highly resistant to biological breakdown. The results of total organic carbon during 140 days of composting process are shown in Appendix B and Figure 4.6.

The variations of organic carbon in all four piles followed a similar decreasing pattern. At the beginning period of the composting process, the organic carbons in all piles were found to be in the range of 37.5 to 44.4%. They decreased continuously throughout the first three months of the composting period. After that, they maintained stable in the range of 16.3% to 18.2% until the end of the experiment.

From the statistical analysis using one-way ANOVA test, it was found that the mean values of total organic carbon contents of four piles were not significantly (*p*> 0.05) different (See Appendix C).

Similar to TVS, the total organic carbon reduction is also the one of the parameters used to determine the maturity of compost. The decrease in total organic carbon associated with time of composting in which explained the decomposition occurring during the composting process. The total organic carbon losses occurred during the first 91 days of composting when the pile temperatures and pH values were above approximate 33 ºC and 7.8, respectively. Under these pH and temperature conditions, the total organic carbon content was found to reach the high rate of decomposition which is similar to the result of Ogunwande *et al.,* 2008 study. However, the aeration from turning process affected on total organic carbon decreasing as well. As a result of this, it was possible that with increased air supply to the piles, carbon served as a source of energy for the micro-organisms and was burnt up and respired as CO_2, or carbon was mineralized, in which affected to carbon lost.

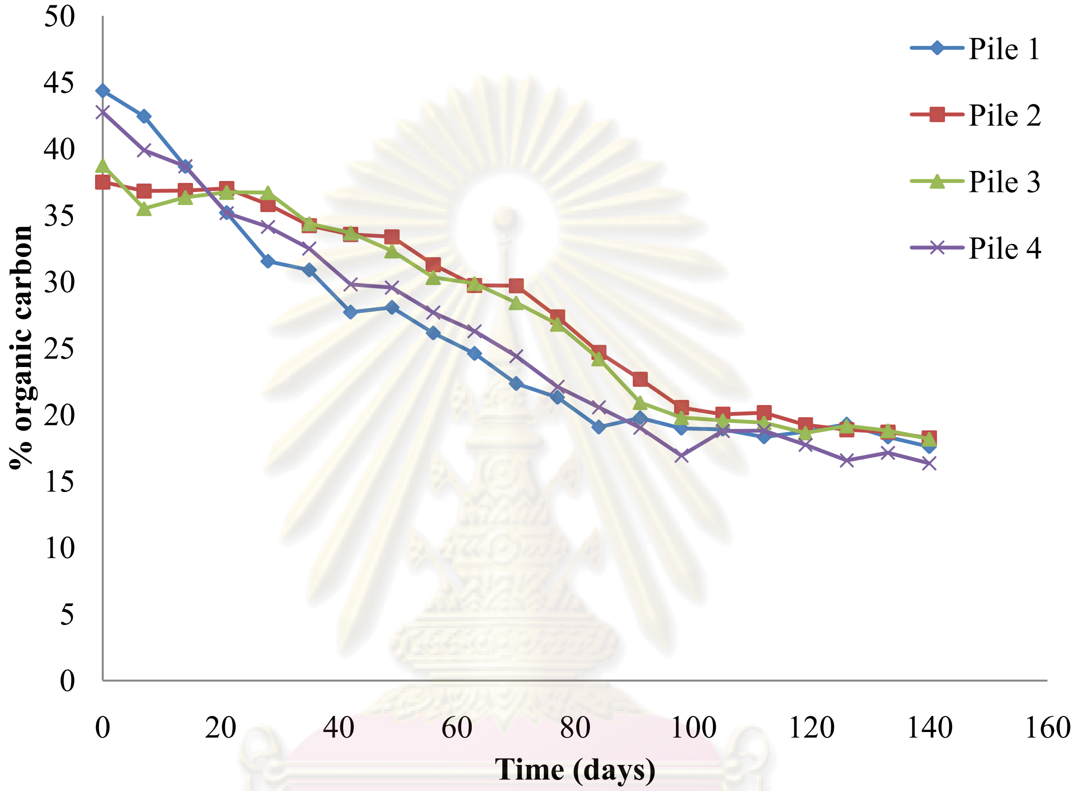


Figure 4.6 The variation of organic carbon in all four piles

4.1.7 Total Nitrogen

Nitrogen is required for the synthesis of microbial cell matter. If nitrogen is not present in adequate amounts, the synthesis will be limited and overall reaction rates reduce from their maximum values due to the absence of nutrient. With nitrogen rich substrates, such as sewage sludge, grass, and most food wastes, nitrogen should be available in adequate amounts without supplement addition. On the other hand, cellulosic materials including tree trimmings, leaves, paper, and some MSW fractions, can be nitrogen poor. In order to provide adequate nitrogen content in composting of this study, the chicken manure was selected to be mixed with wood shaving materials. The results of total nitrogen (TN) during 140 days of the composting process are presented in Appendix B and Figure 4.7.

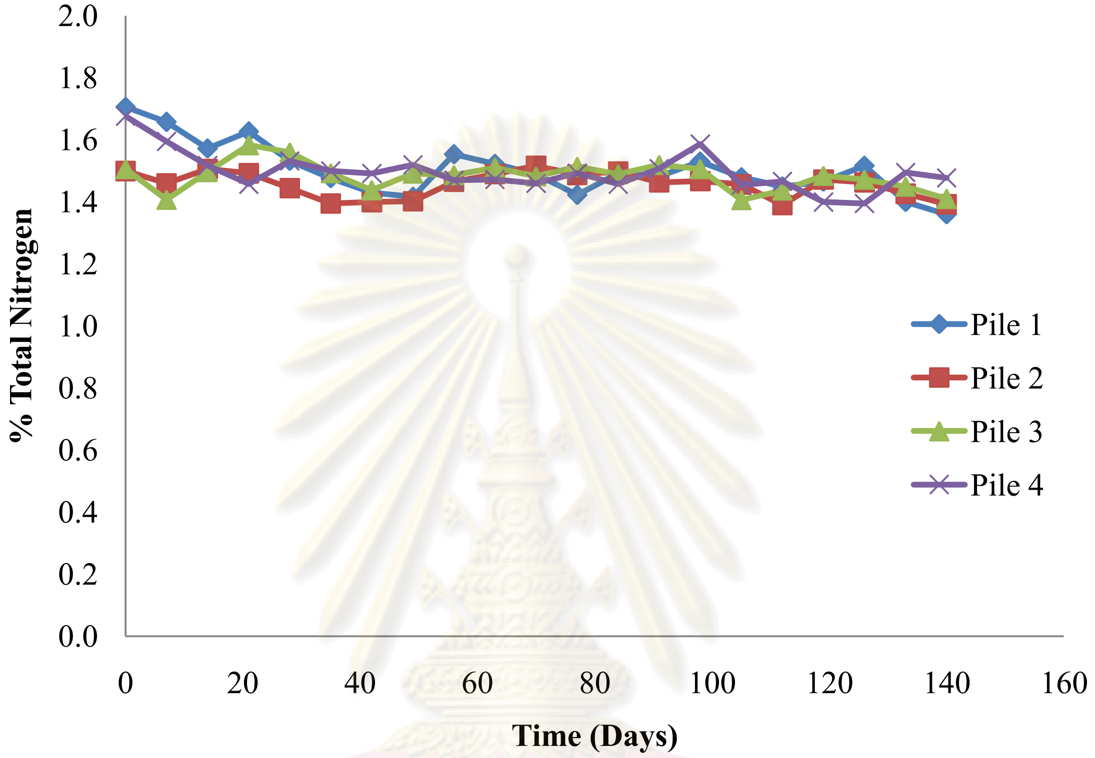


Figure 4.7 The time versus total nitrogen variation during 140 days of composting process.

The results showed that TN values in all compost piles were in the range of 1.5% to 1.71% at the beginning of the composting period. The TN values decreased with time during the first 49 days of the composting process when the temperatures in all piles were higher than 40ºC and pH 8, respectively. As a result, the loss of NH_3 which was transformed from organic nitrogen by microorganisms might be occurred. This result corresponded to other researchers (Tiquia and Tam, 2000; Ogunwande *et al.*, 2008). The TN values of all four piles after 40th day were rather constant. This might be because of the ammonium concentration is eventually reduced through the volatilization and/or oxidation to the nitrate form which was more stable. In addition, the nitrification process occurred mainly during the stable stage when temperatures were close to ambient (Bernal *et al.*, 1998).

From the statistical analysis using one-way ANOVA test indicated that the average values of TN contents during the composting process of four piles were not significantly ($p > 0.05$) different (see Appendix C).

4.1.8 Carbon to nitrogen ratio (C/N)

Requirements with respect to the C/N are functions of the relative differences in amounts of the two elements used by the microbes in the metabolism to obtain energy and the synthesis of new cellular materials. A large percentage of the carbon is oxidized to carbon dioxide by the microbes in their metabolic activities. The remaining carbon is converted into cell wall or membrane, protoplasm, and storage products. The major consumption of nitrogen is in the synthesis of protoplasm. Consequently, much more carbon than nitrogen is required. In this study, the C/N ratios of four compost mixtures were adjusted to be around 25:1 before the proceeding to composting process. The results of C/N ratio variation during 140 days of composting process are shown in Appendix B and Figure 4.8.

The continuously decreasing of C/N ratios starting from around 25 to be 11-13 were investigated at the 100th day of the composting process. After that the ratios were rather stable. The final ratio suggested that all composts had reached the acceptable degree of the maturation, since all the C/N ratios were approximately 13, the limit accepted for mature compost (Bernal et al. 1998). In addition, Saviozzi et al., 1987; Jiminez and Garcia, 1989 also stated that when the C/N ratio is less than 20, the compost is mature and can be used without any restrictions.

The statistical analysis using one-way ANOVA test indicated that C/N ratio during the composting process of all four piles was not significantly ($p > 0.05$) different (see Appendix C).

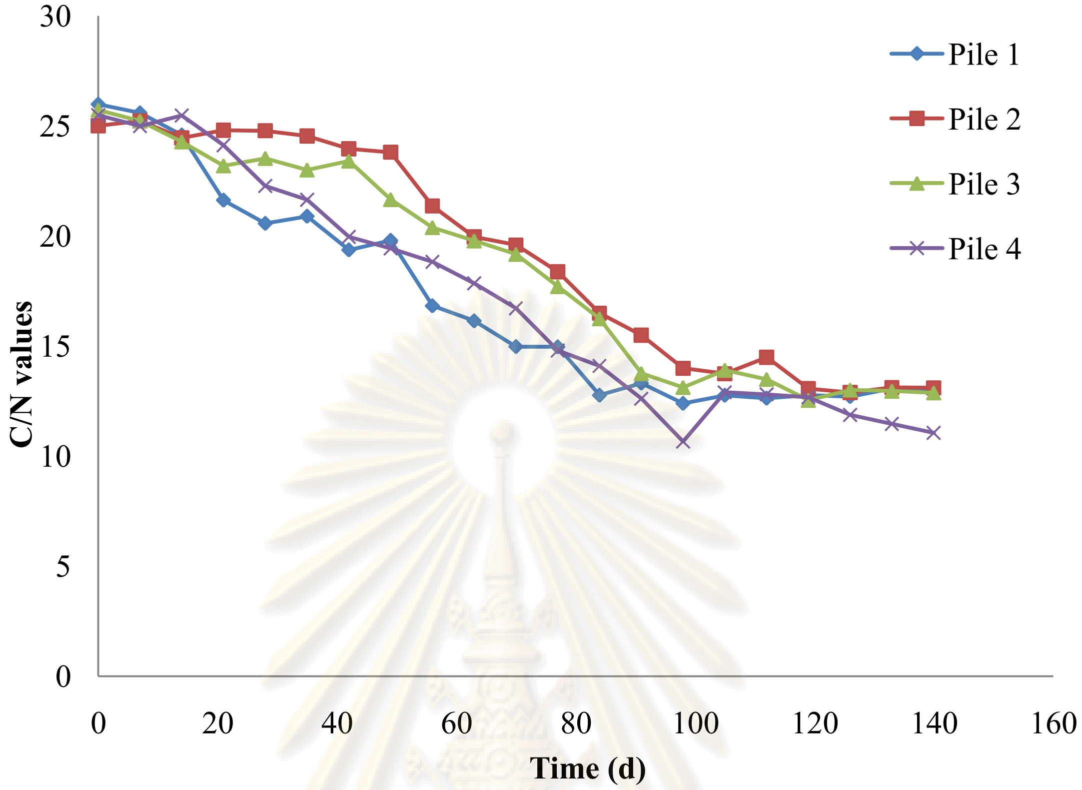


Figure 4.8 The time versus the C:N ratio variation during 140 days of composting process

4.1.9 Germination index (GI)

The germination rate and germination index (GI) are commonly used to assess the phytotoxicity of compost because phytotoxicity is a problem associated with immature composts on toxic substances. Such composts may contain various heavy metals, ammonia and/or low molecular weight organic compounds that may reduce seed germination and also inhibit root development (Tam and Tiquia, 1994). The results of GI variation during 140 days of composting process are shown in appendix B and Figure 4.9.

The germination rate and GI values of *Brassica campertris var. chinensis* seeds increased with time of composting. The GI values of the compost increased from 163, 123, 119, and 114 after 44 days of composting to be about 217, 156, 132 and 114 in pile 1, pile 2, pile 3, and pile 4, respectively at the end of composting.

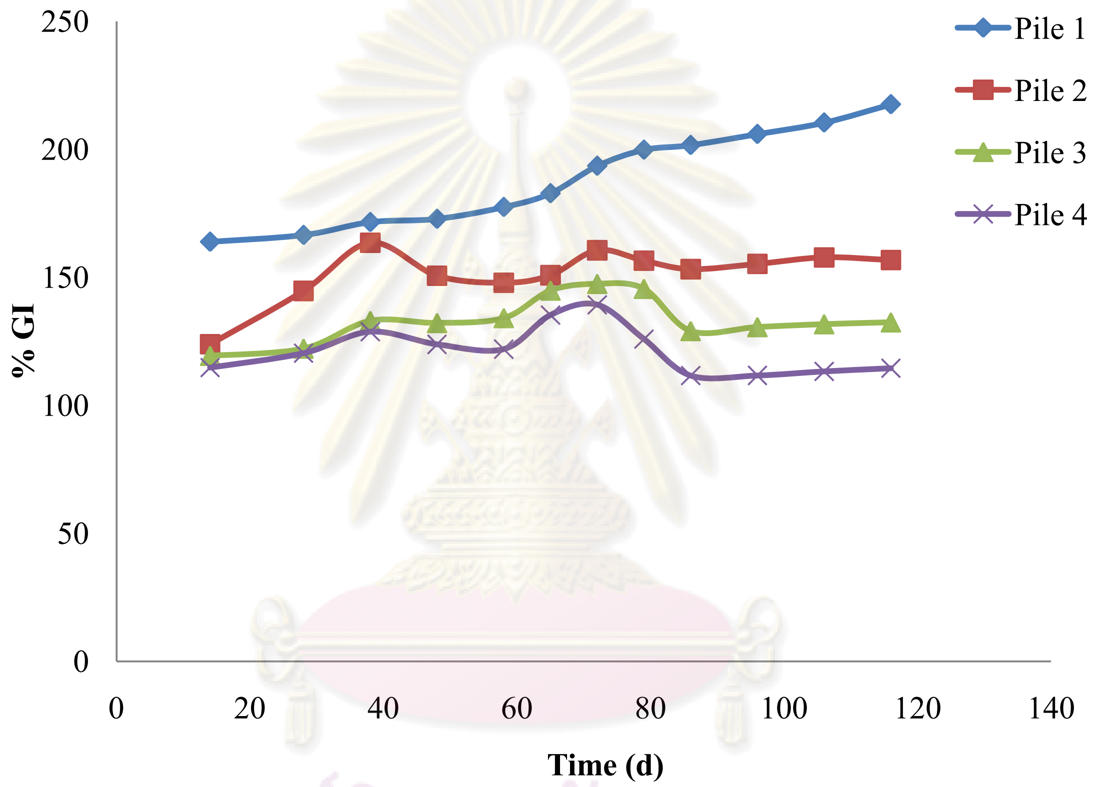


Figure 4.9 The time versus the GI variation during 140 days of composting process

The results clearly showed that the compost pile containing the higher ratio of CCA treated wood had the lower GI values. When composting time proceeded, all GI values increased which indicated that the phytotoxic compounds had been reduced. However, the increasing rate investigated in the pile with CCA treated wood was lower than the pile with non CCA treated wood.

The statistical analysis using one-way ANOVA test indicated that GI values during the composting process of all four piles were significantly ($p < 0.05$) different. When the mean values of the GI values of four compost piles were compared, it was found that compost pile 1 presented the highest value (188.71%) whereas the compost pile 4 presented the lowest value (121.70%).

Zucconi *et al.*, 1981 reported that the compost with GI values greater than 80% was phytotoxin- free and considered as having completed maturity. Similar suggestions were also reported by Tiquia *et al.*,1996, Fang and Wong,1999 and Thai Agriculture Standard (TAS 9503-2005). However, results obtained using the GI should be interpreted with caution, because the GI was affected by the type of seed used and applied extraction rates (Bernal *et al.,* 1998).

It was clearly illustrated all GI values after 2 weeks of composting period exceeded the above mentioned criterion of the phytotoxin-free compost.

4.1.10 Fractions of Cu, Cr and As during composting

4.1.10.1 Total concentration of Cu, Cr and As

The total concentration of heavy metals in the compost is of primary importance. Therefore, it is essential that the amount of these elements in the compost destined for agriculture use does not reach thresholds which can damage either soil fertilization or the food chain. Generally, the total concentrations of Cu, Cr and As of compost presented during composting increase with time due to the decreasing of composting mass. The similar pattern exhibited in this experiment, the total concentrations of Cu, Cr, and As (see Appendix B) gradually increased during 140 days of composting, which is illustrated in Fig 4.10, 4.11 and 4.12, respectively

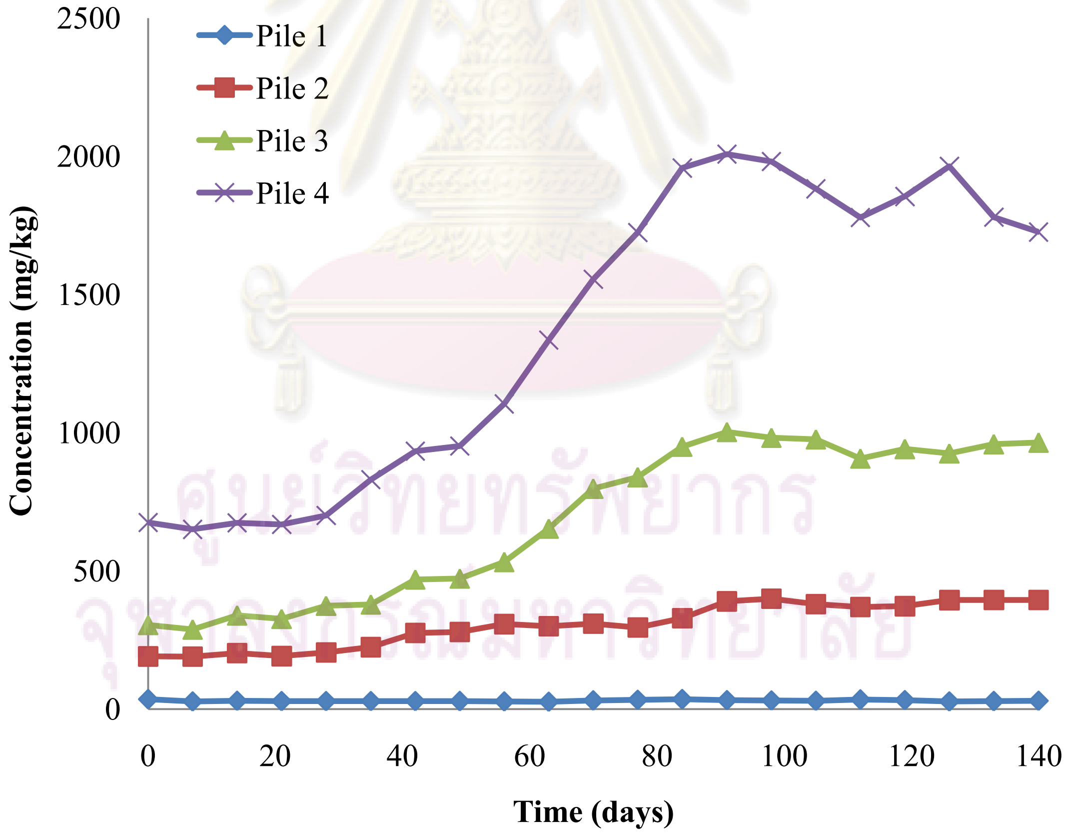


Figure 4.10 The total concentrations of Cu during 140 days of composting process

The total concentrations of Cu of pile 1, 2, 3 and 4 Start with 35.10 mg/kg, 190.38 mg/kg, 304.50 mg/kg and 674.75 mg/kg respectively. The total concentration of Cu gradually increased with time of composting. After 140 days of composting, the total concentration of Cu increased to 29.98 mg/kg, 394.75 mg/kg, 963.88 mg/kg, and 1728.00 mg/kg in pile 1, 2, 3 and 4, respectively. This is represented an increase of 14.60 %, 107.35 %, 216.54 % and 155.80 % in compost pile 1, 2, 3 and 4, respectively. As shown in Figure 4.10, a significant increase in total concentration was observed after 84 days of the composting process, and then the total concentration of Cu became constant. It was found that the Cu concentration in the finish compost of piles 1 and 2 were below (≤ 500 mg/kg) the standard limit of Thai Agriculture Standard (TAS, 9503-2005) whereas those values of pile 3 and 4 were over the limit.

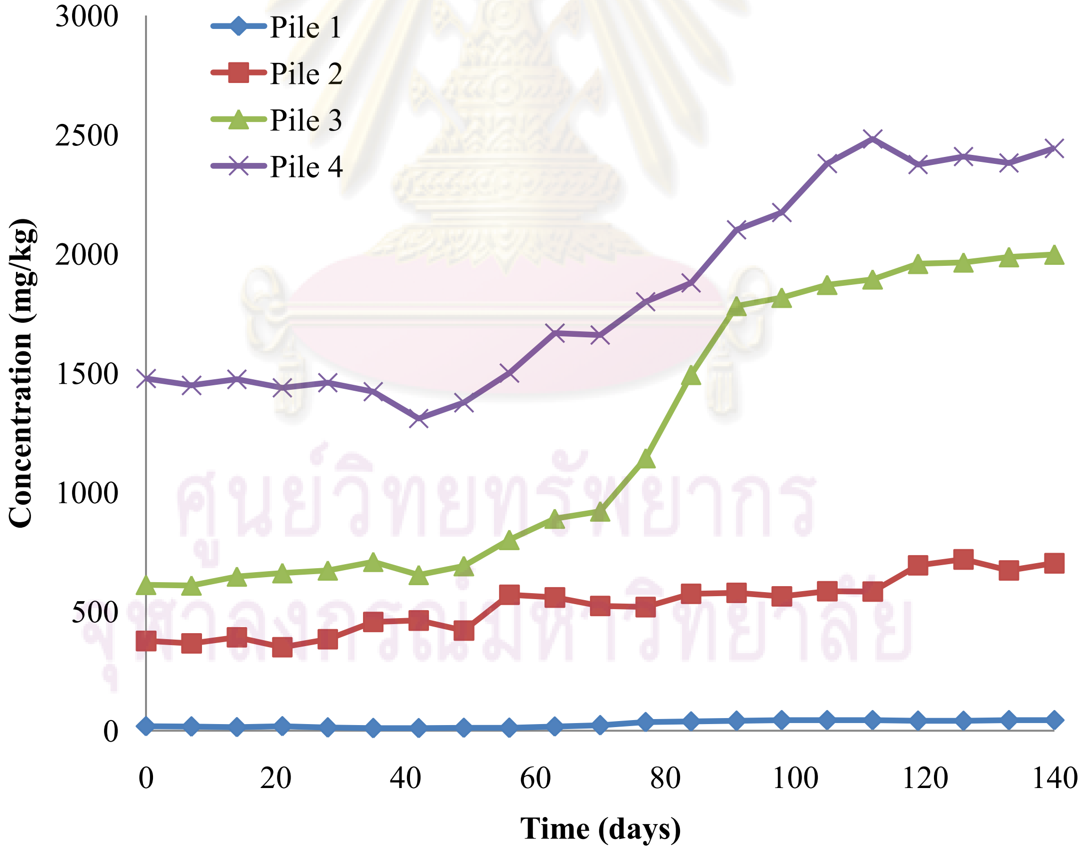


Figure 4.11 The total concentrations of Cr during 140 days of composting process

Figure 4.11 shows that the total concentrations of Cr of pile 1, 2, 3 and 4 increased steadily over 140 days of composting, increasing from 18.88 mg/kg, 376.50 mg/kg, 612.30 mg/kg and 1476.80 mg/kg to 44.73 mg/kg, 702.50 mg/kg, 1997.13 mg/kg, and 2442.50 mg/kg in pile 1, 2, 3 and 4, respectively. The increasing of total concentrations during composting process were represented to be 136.89 %, 86.56 %, 226.17 % and 65.38 % in pile 1, 2, 3 and 4, respectively. This appeared to occur slowly during the first 77 days, and more rapidly thereafter until remain constant at the last 14 days of composting. As has been known, the heavy metal concentration in the composting materials has significant effect on metal condensation. The CCA treating substance presented has great deal with the heavy metal content in the finish compost products. In case of Cr content, it was found that the Cr concentrations of pile 2, 3 and 4 were over the limit of Thai Agriculture Standard for compost (≤ 300 mg/kg) (TAS, 9503-2005). Only in pile 1, which no CCA treated wood was added, the total Cr concentration was below that limit.

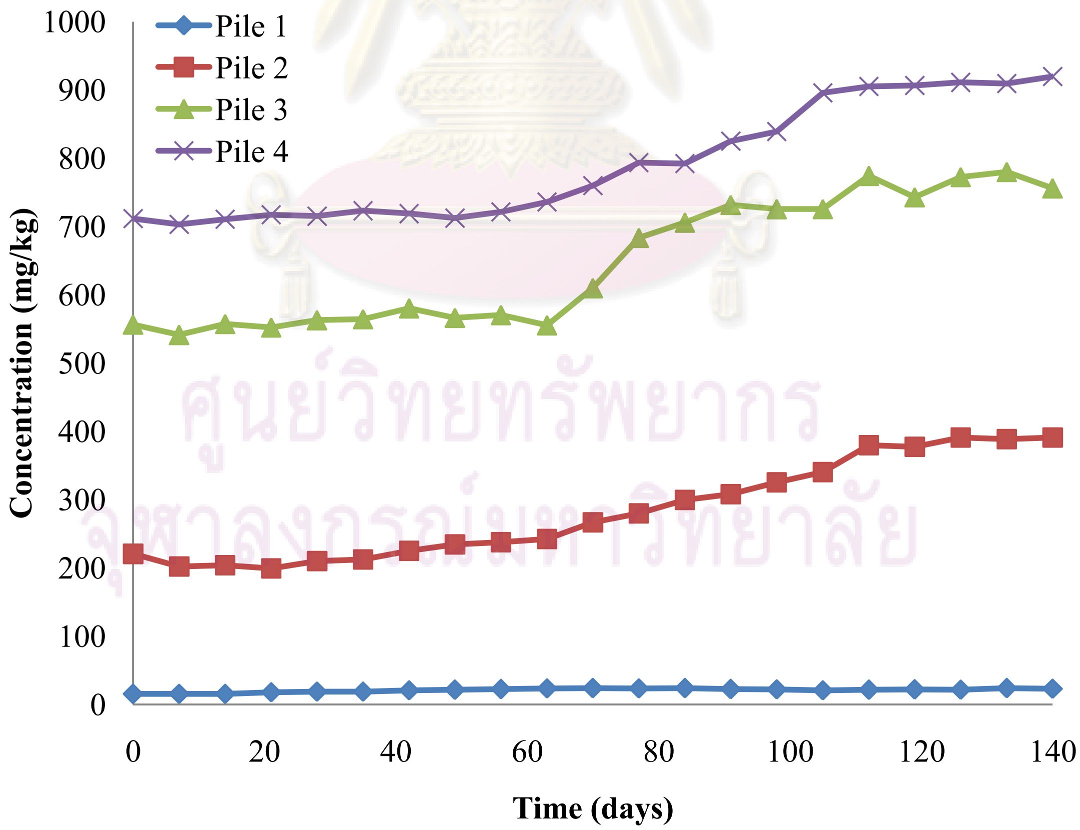


Figure 4.12 The total concentrations of As during 140 days of composting process

As indicated in Figure. 4.12, the gradually increasing in total metal concentration was observed for As during the composting process. The total concentration of As increased from 15.32 mg/kg, 220.68 mg/kg, 556.35 mg/kg and 711.75 mg/kg at the start of composting period to 22.98 mg/kg, 391.15 mg/kg, 756 mg/kg, and 919. 63 mg/kg, in which represented an increase of 49.99 %, 77.25 %, 53.86 % and 29.2 % in compost pile 1, 2, 3 and 4, respectively. However, only the total concentration of As in the finished compost from piles 1 were below the Thai Agriculture Standard limit (≤ 50 mg/kg) (TAS, 9503-2005) because no CCA-treated wood shaving was mixed into this pile.

As illustrated in Figure 4.10, 4.11 and 4.12, the Cu, Cr and As in the compost mixture from all piles were concentrated during the composting process, which were in accordance with the results reported by Wagner *et al.,* 1990, Canaruttto *et al.,* 1991 and Lui *et al.,* 2007, due to weight loss in the course of composting following organic matter decomposition, release of CO_2, water, and mineralization processes.

The statistical analysis indicated that the average concentrations of all three metals in all four compost piles were significantly different ($p< 0.05$) (see Appendix C). As expected, the compost pile 4 showed the highest total concentrations of all three heavy metals during the composting due to their highest CCA treated wood presented. Therefore, it can be concluded that the proportions of CCA treated wood influenced the total concentration of three metals in the four piles.

With regard to the proportion of metals content in four composted piles, the Cu, Cr and As proportions ranked in the following order: Cr > Cu > As, except in compost pile 1 which no CCA treated wood presented. The proportions of Cu, Cr and As of all four compost piles during the composting process are shown in Figure 4.13 below.

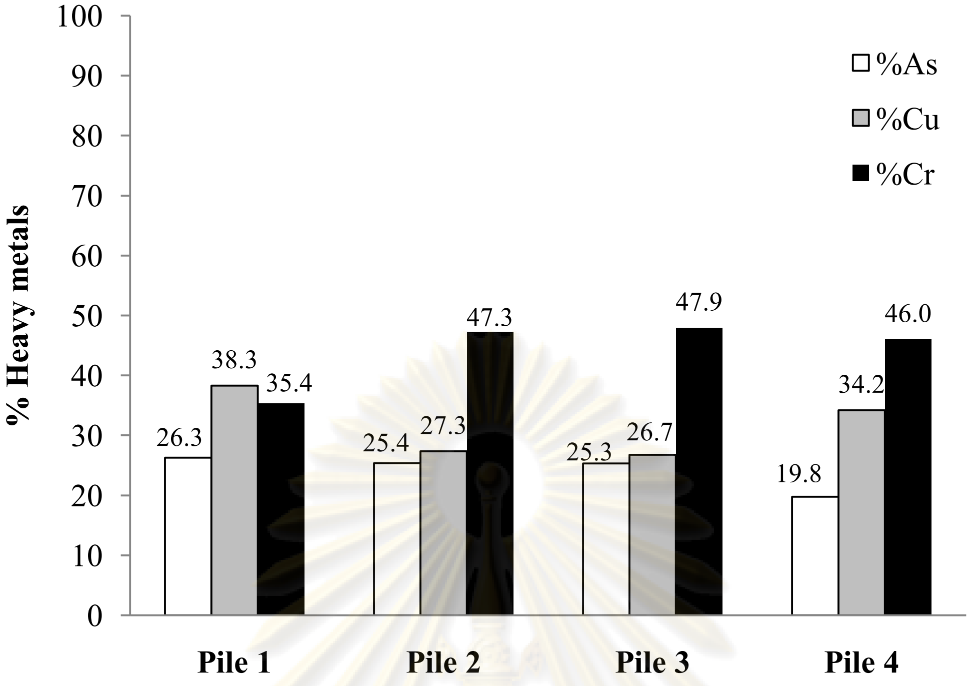


Figure 4.13 The proportions of Cu, Cr and As of four compost piles during composting

The proportions of Cu, Cr and As concentration presented in this study was affected by the amount of CrO_3, CuO and As_2O_5 consisted in CCA treating solution. Due to the information of CCA applied in the treatment of the wood wastes used in this study were not clearly identified by the wood factory. The information of Cu, Cr and As in Table 2.1 was selected to compare with the results obtained in this study. It was found that the percentage of Cu content were different from the specified ratio presented in Table 2.1, whereas the percentages of Cr and As were closed to the ratios of Cr and As in CCA-type A, and C, respectively.

Because of the CCA treated wood used in this study mostly were the CCA treated wood wastes piled up in an outdoor area for more than 2 years. Therefore, during rain, water might penetrate into the wood pile and caused leaching of heavy metals. Moreover, the wood materials used in this study were mixed types of wood and some of these wood materials were used as a supporting frame in the treating process for several times.

4.1.10.2 Change of Cu distribution during composting

Copper is one of several heavy metals that are essential to life despite being as inherently toxic as non–essential heavy metals exemplified by lead and mercury. In his study, the following six fractions were determined using a sequential extraction procedure; water soluble (F1), exchangeable (F2), carbonate-bound (F3), Fe/Mn oxide bound (F4), organic matter/sulfide bound (F5), and residual (F6). The fraction percentages of Cu obtained from the sequential extraction are presented in Figure. 4.14.

During composting, the variations of the Cu-F1, Cu-F2 and Cu-F3 distributions were trivial, compared with other fractions. Most of the Cu in all piles (>50%) existed in the Fe/Mn fraction (F4) at the initial phase of the composting. There was a fluctuation in the proportion of Cu in pile 1, which was not amended with CCA-treated wood. The Cu-F5 in pile 1 decreased with time and was redistributed to the residual fraction after 70th day of the composting. The percentages of Cu-F4 in pile 1 and 2 were high during 140 days of the composting process. For pile 3 and 4, Cu was associated with F4 during the first 80 days of composting. During the day 40th-80th of composting, there was a trend of pH decreasing which accelerated the mobilization of heavy metal, especially in mobile phase (Simpson *et al.,* 2002). It was found that the percentages of Cu-F4 in pile 2, 3 and 4 decreased with time of composting. From day 1st to 140th of composting process, there was a significant decreasing of Cu-F4 in pile 2, 3, and 4 to 33.7%, 32.1% and 43.5%, respectively, while the Cu-F5 and Cu-F6 increased. After day 70th and 84th of composting, the Cu-F4 resembled to be transferred into a stable phase in pile 3 and 4. After this change, it was found that more than 50% of Cu was found in the stable fractions (F5 and F6). It was also found by other researchers that Cu was mainly present in the organically bound fraction (F5) in the finished compost of sewage sludge (Nomeda *et al.,* 2007 and Zorpus *et al.,* 2008). The increasing of Cu in organically bound fraction were possibly due to the released heavy metal from the lower pH condition in the prior period (during the day 40th-80th of composting) were easily combined with organic matter in the compost mixture. Moreover, it was found that some parts of Cu during the composting process were significantly transferred from mobile fraction to organic bound and residual fraction during the composting process. In general, Cu was not easily mobilized in the composting process due to its high affinity to organic matter.

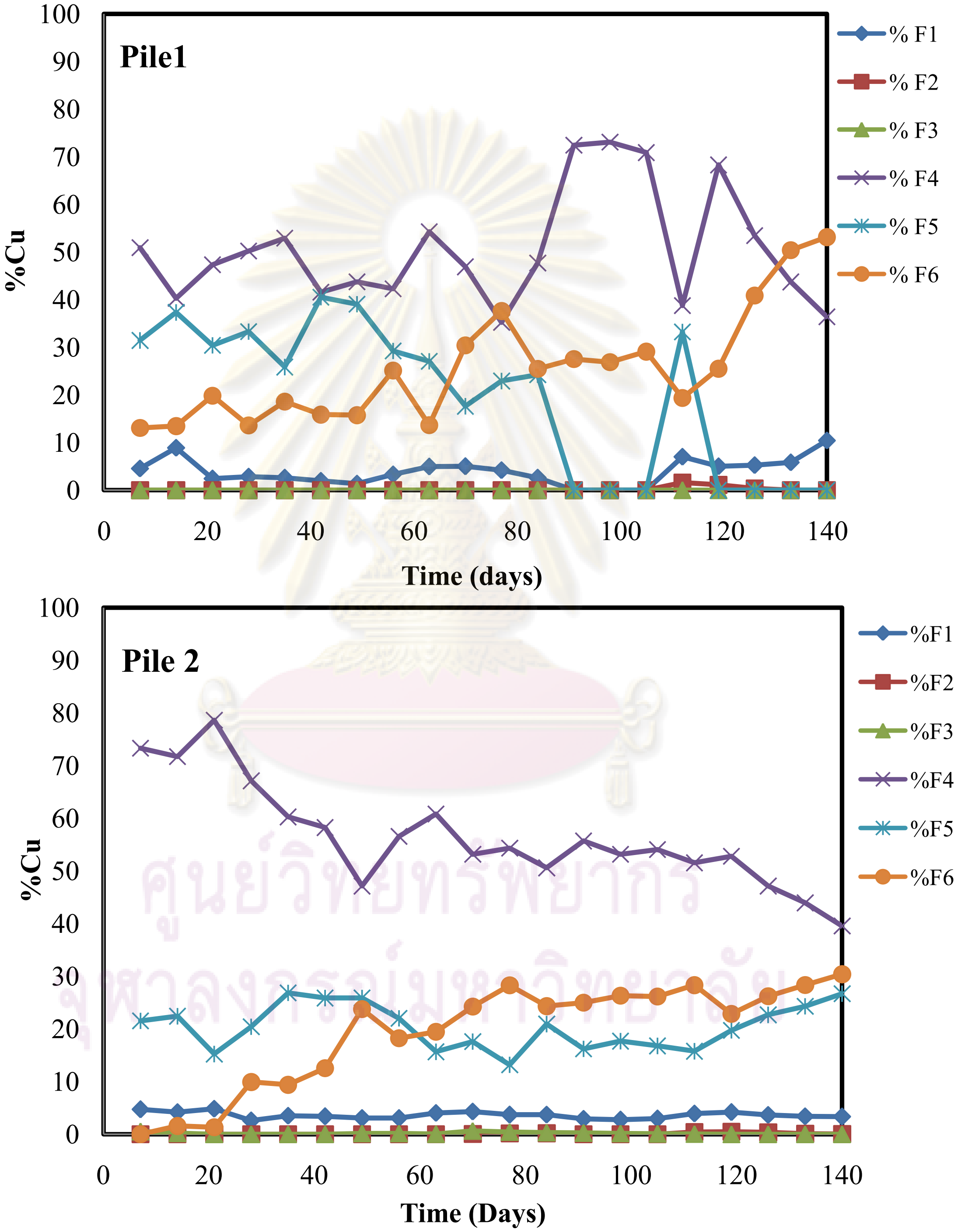


Figure 4.14 The variation of six fractions of Cu in four compost piles during composting

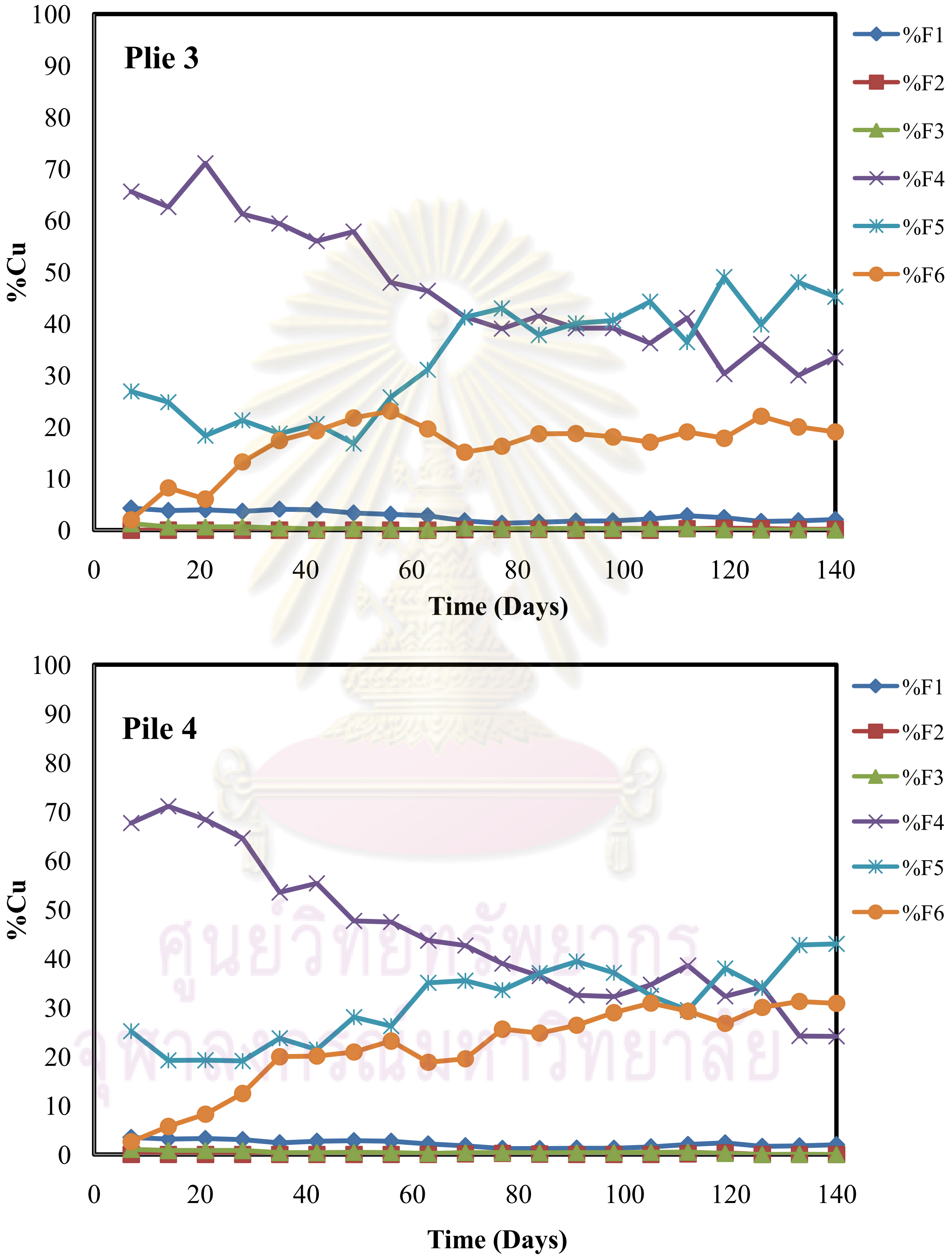


Figure 4.14 The variation of six fractions of Cu in four compost piles during composting (continued)

4.1.10.3 Change of Cr distribution during composting

Chromium is an element found in many minerals which are widely distributed in the environment. In wood preservative, Chromium promotes fixation of the Cu and As in the wood through the formation of sparingly soluble metal complex, such as $CuCrO_4$ and $CrAsO_4$ (Pizzi, 1982). After the end of useful service life, about 20 to 40 years, Cr is loosely bound to the wood and can be partially washed out by infiltration and/or rain water. By this way, Cr will finally reach the environment. To understand the fate of Cr from wood preservative is of importance due to their high toxicity. Similar to Cu, the six fraction of Cr during composting were investigated and the results is presented in Figure 4.15.

During the thermophillic phase (40 days of composting), the organic fraction (Cr-F5) of Cr in all piles were higher (>50%), than other fractions. It could be explained that, in the CCA treating solution, Cr acts as a fixing agent to precipitate As and Cu onto the wood when Cr(VI) is reduced to Cr(III). This function of Cr in the CCA fixation process implies that Cr easily forms a complex with wood and thus most Cr is associated with organic matter (Pan *et al.,* 2009). During the thermophillic phase, the percentages of Cr-F5 gradually decreased, their reduction were about 58.9%, 26.9%, 37.9%, and 25.9% in pile 1, 2, 3 and 4, respectively. These declines were also found in Cr-F4 with a reduction of 4.1%, 10.2%, 18.4%, and 24.8% in pile 1, 2, 3 and 4, respectively. In contrast, all compost piles showed a significant increase of the Cr-F6 fraction during composting. The variation of Cr might be affected by the temperature change. Actually, the temperature exerts an important effect on metal speciation, because most chemical reaction rates are highly sensitive to temperature changes (Elder, 1989). An increasing of temperature also increases biochemical reaction rates, which are the driving force in composting conditions and enhance the tendency of metals speciation change. Temperatures affect the biological process rates typically double with every 10 ºC temperature increment (Luoma, 1983; Prosi, 1989). Therefore, the changes of metal portions were mostly occurred during the high temperature, especially in the thermophillic phase.

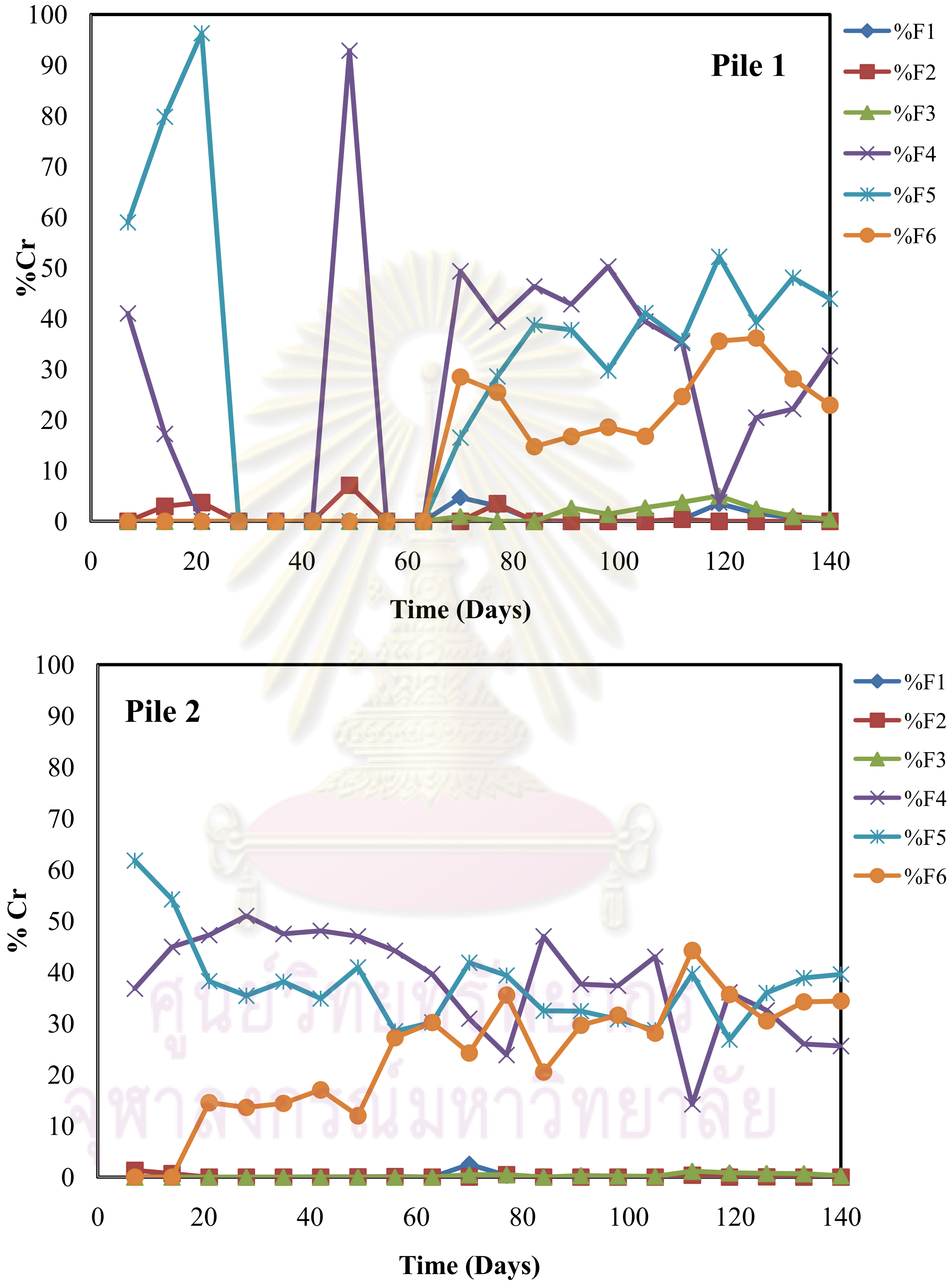


Figure 4.15 The variation of six fractions of Cr in four compost piles during composting

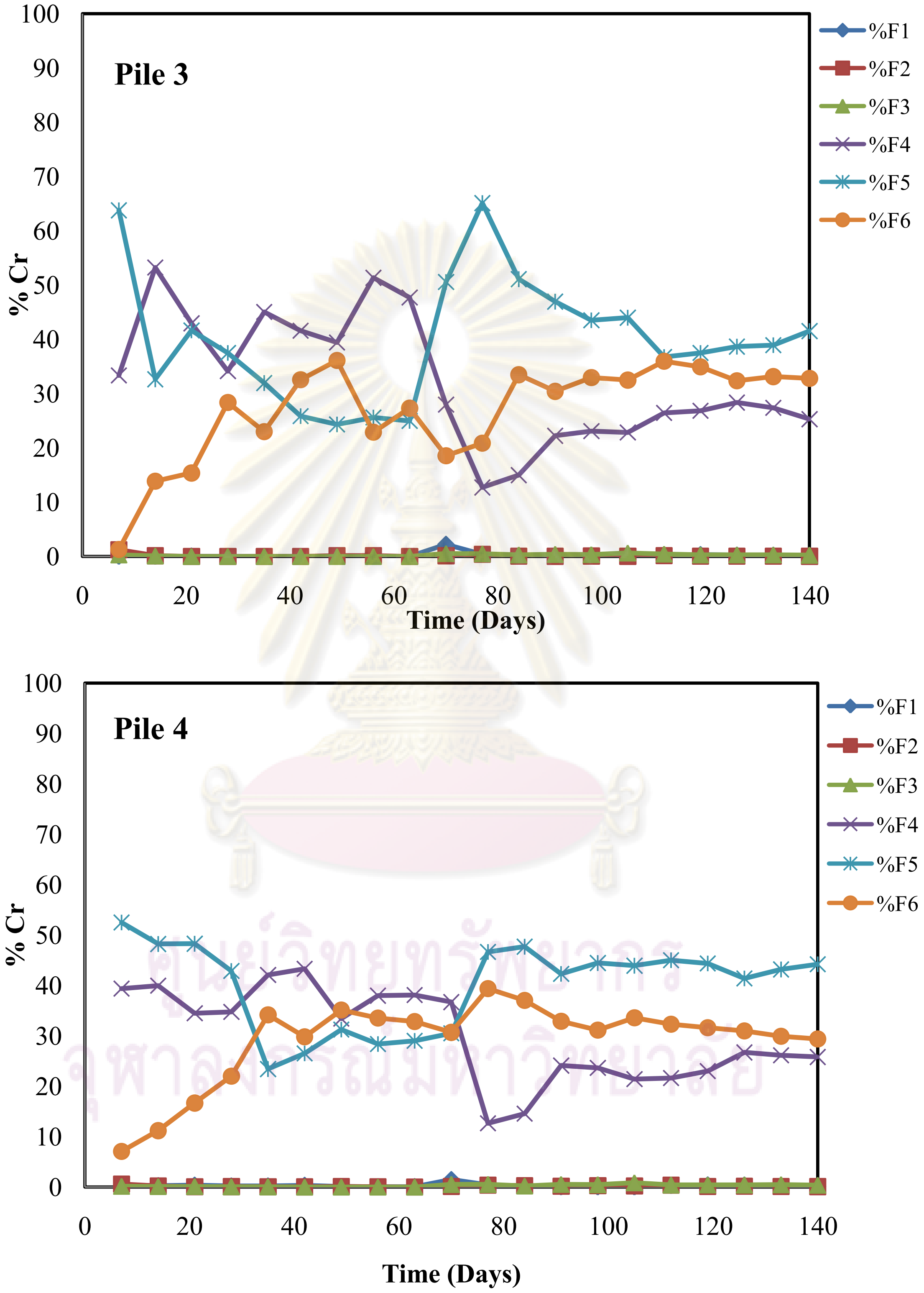


Figure 4.15 The variation of six fractions of Cr in four compost piles during composting (continued)

Similar to the results obtained from Zorpus *et al.,* 2004 who investigated the heavy metal fractionation during the composting of tannery sludge. They found that high proportion of Cr was present more in the stable phase. These may be due to the fact that most Cr(III) compounds are soluble only under low pH values. At the pH values above 5 to 6, Cr(III) generally precipitate and stable trivalent chromium complexes can be formed (Gmelin, 1962). Moreover, Chromium is classified as a low water soluble metal which is generally less mobile (Henry and Harrison, 1997). However, as discussed in the study of heavy metal fractionation during tannery sludge composting process from Mahdi *et al.,* 2007, the fate of Cr dependents upon the form in which it exists within the materials.

4.1.10.4 Change of As distribution during composting

The most frequent application of arsenic salts are used to be in the preparation of insecticide, mainly as form of arsenate compound and less frequently as arsenite compound. Arsenicals are found in other applications as herbicides, desiccants to facilitate mechanical cotton harvesting, fungicides, algicides, sheep dips, and wood preservative (Peterson *et al.,* 1981; Newland, 1982). Because of occupational and environment risks, these uses are decreasing. In CCA treating solution used, arsenic used in form of pentavalent arsenic (As_2O_5) oxides. Special provisions for storage and handling of arsenical products have to be taken. To enhance the understanding of this, the fate of As in its fractionation can be indicated the bioavailability which possibly enter to environment. The six fractions of As investigated in this study are presented in Appendix B and Figure 4.16.

As shown in Figure. 4.16, the As distributions in the four composts show a similar trend during composing. The form of As was mainly present in the oxidizable fraction (As-F5) at the initial composting phase, accounting for around 49%, 38.8%, 31.2%, and 27.8% of compost pile 1, 2, 3 and 4, respectively. During the composting process, the As-F5 dramatically decreased, while the As-F1 and As-F2 increased.

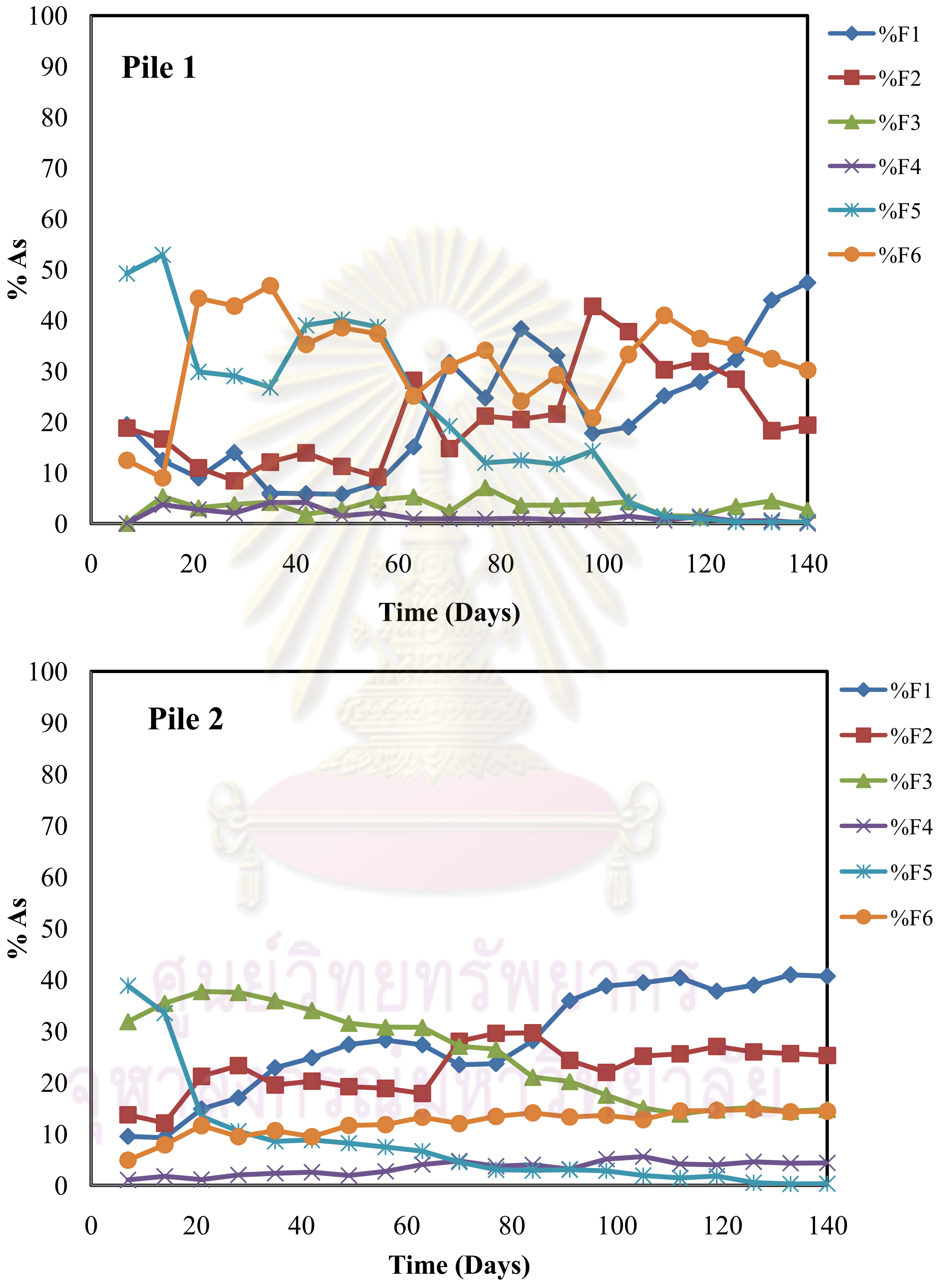
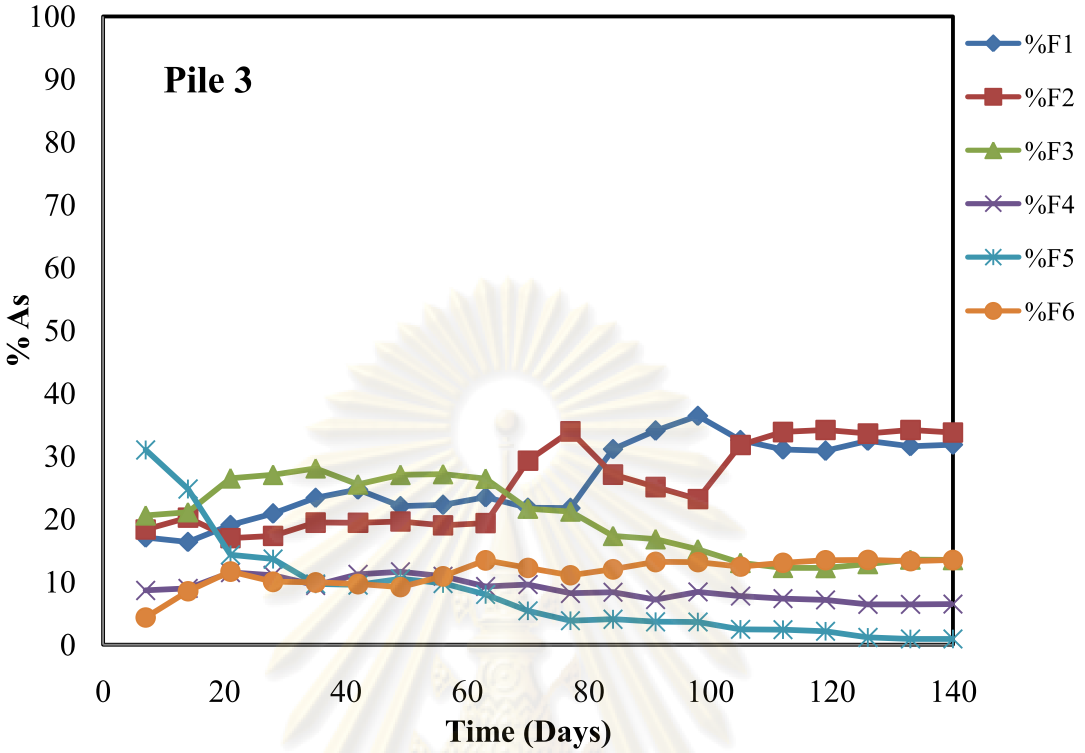


Figure 4.16 The variation of six fractions of As in four compost piles during composting



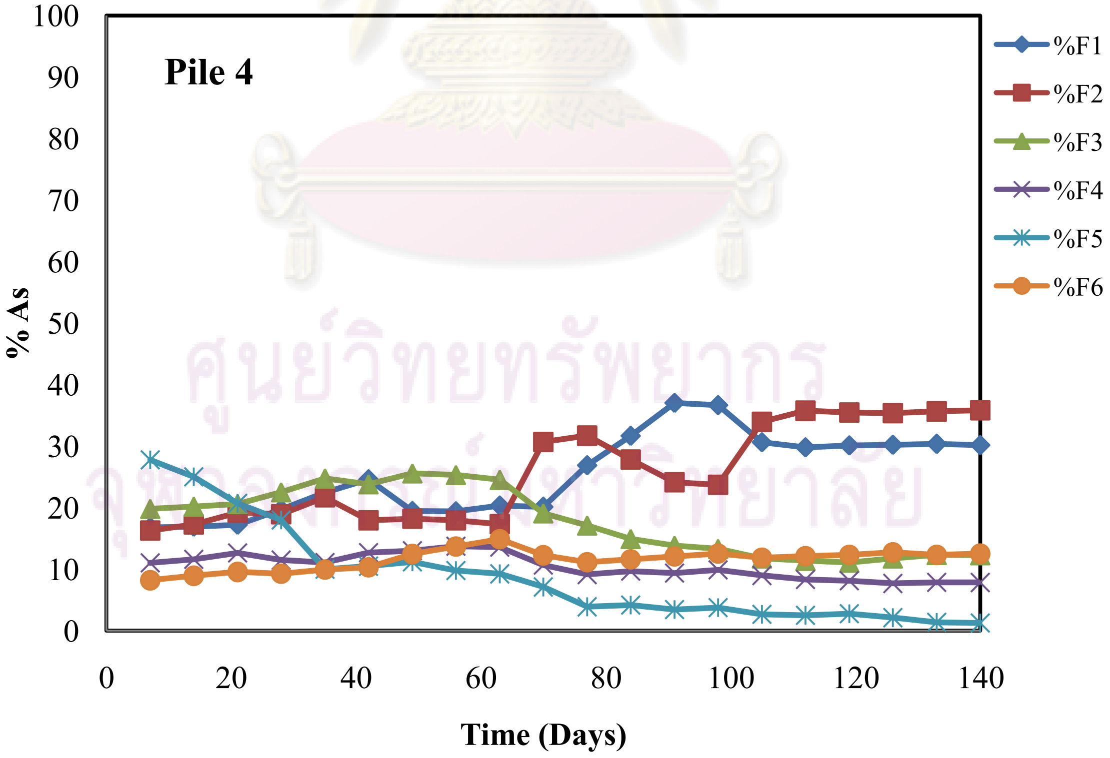


Figure 4.16 The variation of six fractions of As in four compost piles during composting (continued)

The As-F4 and As-F6 showed less variation and seemed to remain constant during the composting, except in pile 1 which was not amended with CCA-treated wood. Generally, most As should be fixed in wood after fixation process and associated with organically bound fraction (Pan *et al.,* 2009) which result in the higher percentage of As at the initial. During composting, the organically bound fraction was transformed to the soluble and exchangeable fraction and therefore it can be assumed that fixed arsenic was gradually released from the wood due to changes of the chemical environment during the composting process. It has been reported that the changes in pH and temperature greatly affect the leaching of As (Lebow *et al.,* 2008). Therefore, during the lower pH condition of composting and the reduction of wood mass, the water soluble and exchangeable fractions could also come from the As that failed to fix onto wood and may undergo reversed reaction of the fixation process under the lower pH condition and further convert insoluble CCA compounds into more soluble compounds (Kartal and Clausen, 2001).

4.1.11 Compost masses

Generally, the total mass of materials in compost pile would be reduced with time of the composting process results from the decompositions of organic materials taking place during the composting process. The results of the total dry mass reduction obtained during this study are presented in Table 4.2. It was found that the compost mass reduction was in the range of 29.27% - 39.22% which was corresponded to the mass reduction found in other general organic compost material. (Tiquia, *et al.*, 2002)

Table 4.2 Total mass reduction during composting process

Compost piles	**Compost mass, kg (% dry weight)**			**% mass reduction**
	Start	**Finish**	**Mass loss**	
Pile 1	65.30	40.85	24.45	37.44
Pile 2	64.47	42.91	21.56	33.44
Pile 3	61.23	43.31	17.92	29.27
Pile 4	65.22	39.64	25.58	39.22

4.1.12 Heavy metal mass balance

The masses of Cu, Cr and As during composting process associated with the total mass of materials in each compost pile and the total concentrations of heavy metals content. The masses of Cu, Cr and As during composting process are shown in Table 4.3. It was found that Cu and Cr masses generally increased at the end of the composting period.

Table 4.3 The results of mass balance of Cu, Cr and As during composting process

	Pile no.	**Total concentration (mg/kg)**		**Sample weight (kg.dry wt)**		**Metal mass (g)**	
		Start	**Final**	**Start**	**Final**	**Start**	**Final**
Cu	Pile1	35.1	29.9	65.31	40.86	2.29	1.22
	Pile2	190.4	394.7	64.47	42.91	12.27	16.94
	Pile3	304.5	963.8	61.23	43.31	18.65	41.75
	Pile4	674.8	1726	61.19	42.69	41.29	73.69
Cr	Pile1	18.8	44.7	65.31	40.86	1.23	1.83
	Pile2	376.5	702.5	64.47	42.91	24.27	30.15
	Pile3	612.3	1997	61.23	43.31	37.49	86.50
	Pile4	1476	2442	61.19	42.69	90.37	104.3
As	Pile1	15.3	22.9	65.31	40.86	1.00	0.94
	Pile2	220.7	391.1	64.47	42.91	14.23	16.79
	Pile3	556.4	756.0	61.23	43.31	34.07	32.74
	Pile4	711.8	919.6	61.19	42.69	43.55	39.26

4.1.13 Overview of composting process

In summary, the characterization of compost exhibited in this study indicated that the decomposition was activated in all four piles during the composting process. No significant differences of the variations of temperature, pH, moisture content, TVS, total organic carbon, TN, and C/N of all four piles were investigated. Composting of CCA-treated wood did not seem to have any influence on the decomposition of organic matter during the composting process in this study. However, the GI values (Figure 4.9) of all four piles show significant differences among the four compost piles. As a result, it can be indicated that the amount of heavy metal consisting in the compost had an effect on the seed germination. However, it should be remarked that all GI values obtained in this study were still higher than Thai Agriculture Standard and other researchers suggestion (Zucconi *et al.*, 1981; Tiquia *et al.*,1996; Fang and Wong,1999 and TAS 9503-2005) which mean that all composts would have no any phytotoxicity.

4.2 Metal plant uptake

4.2.1 Distribution of heavy metals in soil amended compost.

4.2.1.1 Total concentrations of Cu, Cr, and As

Heavy metals ions included in soil material are set free in the process of soil formation. The further fate of the ions depended on many factors such as pH, humus content, redox potential as well as external factor such as temperature, precipitation, erosion land use practice etc. Accordingly, some elements are accumulated in soil materials whereas others are leached out. Consequently, some metals were possibly uptaken and accumulated by plant. In addition, the amount of heavy metal content in soil varying with the metals supplied by dry and wet deposition and by agronomic practices (e.g., compost, sewage sludge). The utilization of compost amended soil was considered as main route which supplied heavy metal to plant. In this study, the compost of CCA treated wood and chicken manure was used to amend with soil during *Brassica campertris var. chinensis* planting. Due to the chemical composition of CCA, the heavy metal contents in these compost amended soils were associated with three metal elements; Cu, Cr, and As. The total concentrations of Cu, Cr and As in soil during 45 days of *Brassica campertris var. chinensis* planting are shown in Figure 4.17, 4.18, 4.19, and Appendix B.

During the 45 days of *Brassica campertris var. chinensis* planting, it was found that the total concentrations of Cu, Cr, and As in all soils slightly decreased with time. Similar result in a decreasing of the Cu concentration in soil as influenced by compost amendment was also reported by Farrell *et.al.,* (2009) who studied the migration of heavy metals in soil as influenced by green wastes and MSW compost amendments. In contrast with the results obtained from Akkarabanthid (2004) who planted Chinese kale with compost contaminated with Cu and found that the total concentrations of Cu of Chinese kale planting increased with time. However, the heavy metals in soil and compost are able to distribute and change to plant uptake available forms, depending on their geochemical and environmental processes present. Therefore, Cu, Cr and As contents in the soils used in this study might be changed into the available forms for plant uptake and mobilize via the soil solution. The following results of the fractionation of Cu, Cr, and As in soil during planting may explain the metal transformation properly.

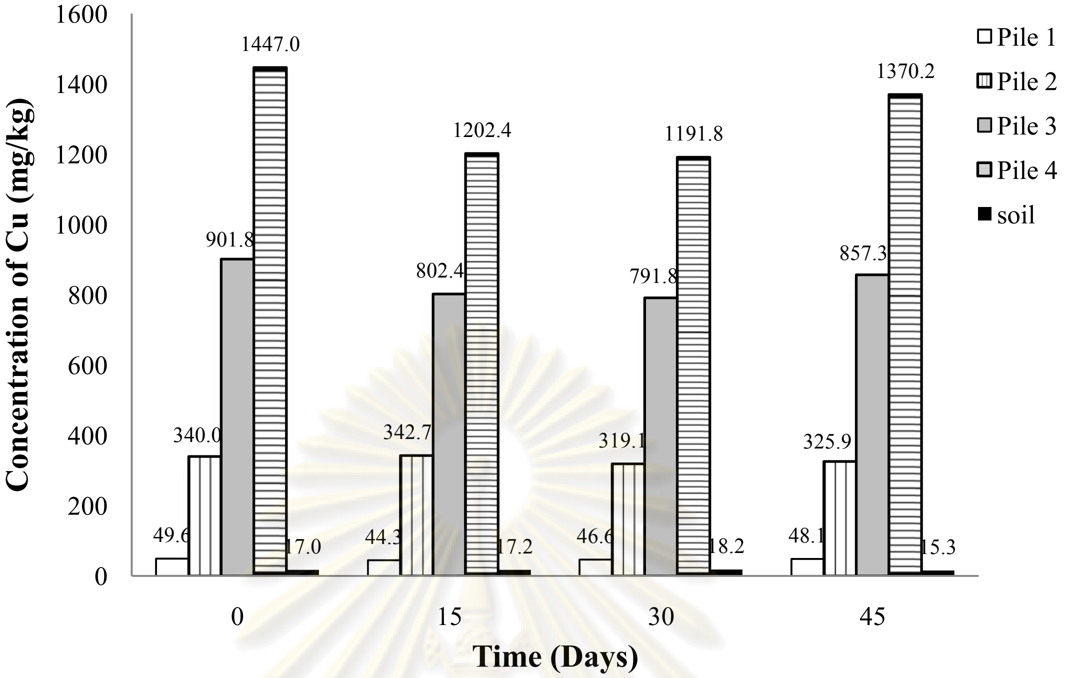


Figure 4.17 Total concentrations of Cu in soil and soil amended with compost during 45 days of *Brassica campertris var. chinensis* planting

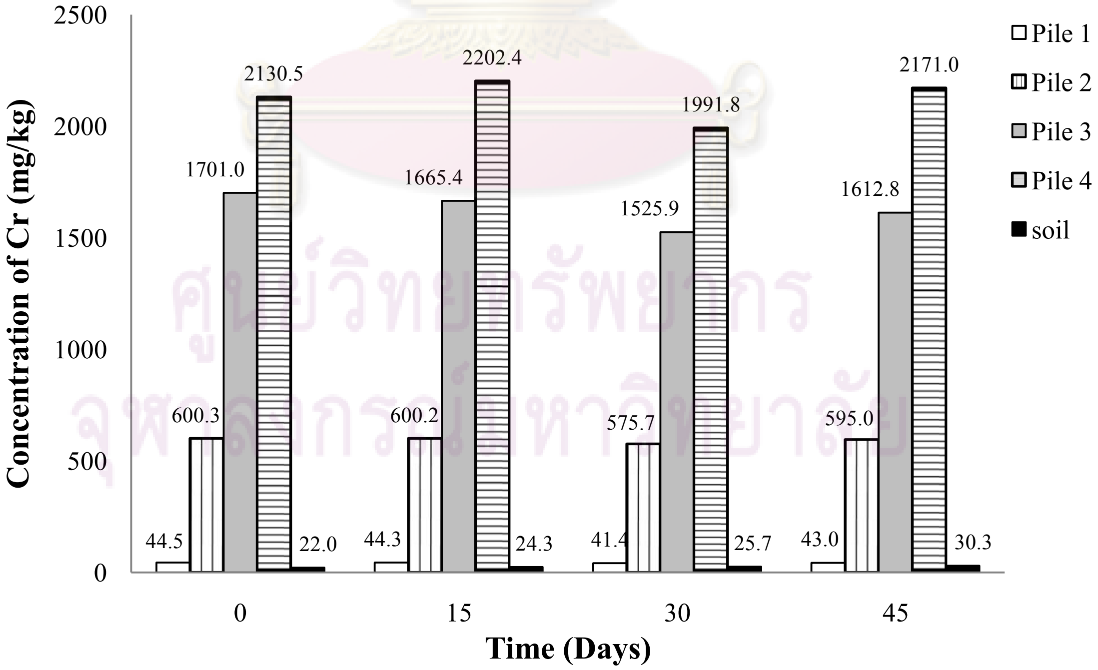


Figure 4.18 Total concentrations of Cr in soil and soil amended with compost during 45 days of *Brassica campertris var. chinensis* planting

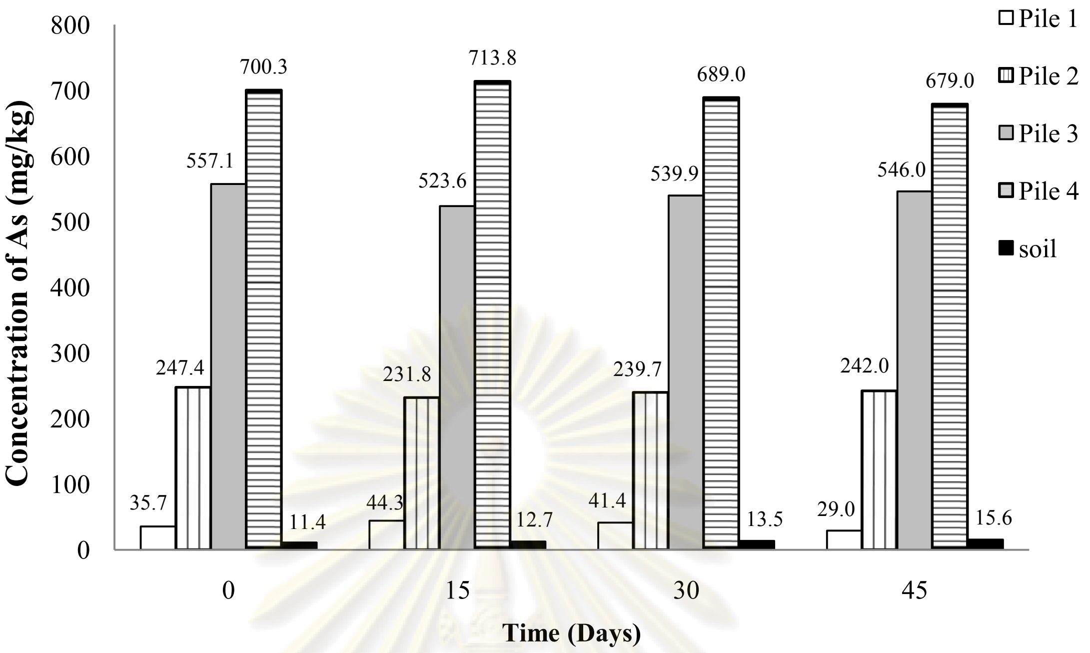
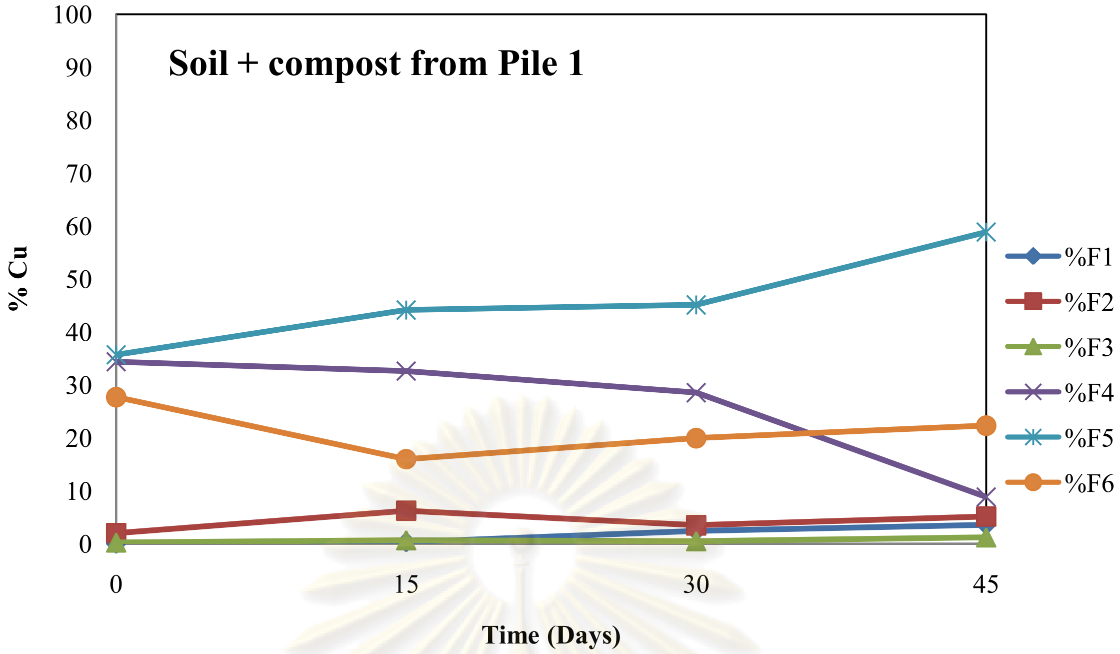


Figure 4.19 Total concentrations of As in soil and soil amended with compost during 45 days of *Brassica campertris var. chinensis* planting

4.2.1.2 Fractionations of copper in soil and soils amended compost during planting process

The results of Cu in soil and soil amended composts during 45 days of planting process are shown in Figure 4.20.

During planting, the variations of the Cu-F1, Cu-F2 and Cu-F3 proportions were trivial, compared with other fractions. The tendencies of these Cu-F1, Cu-F2, and Cu-F3 show increasing with time. Firstly, most of the Cu in all piles (>30%) existed in the Fe/Mn fraction (F4) and organic bound fraction (F5). After planting process started, the proportion of F4, F5, and F6 obviously changed. The Cu-F5 increased while the Cu-F4 gradually decreased with planting time. Similar changing pattern of Cu-F4 and Cu-F5 were also found in Akkarabanthid (2004) study.



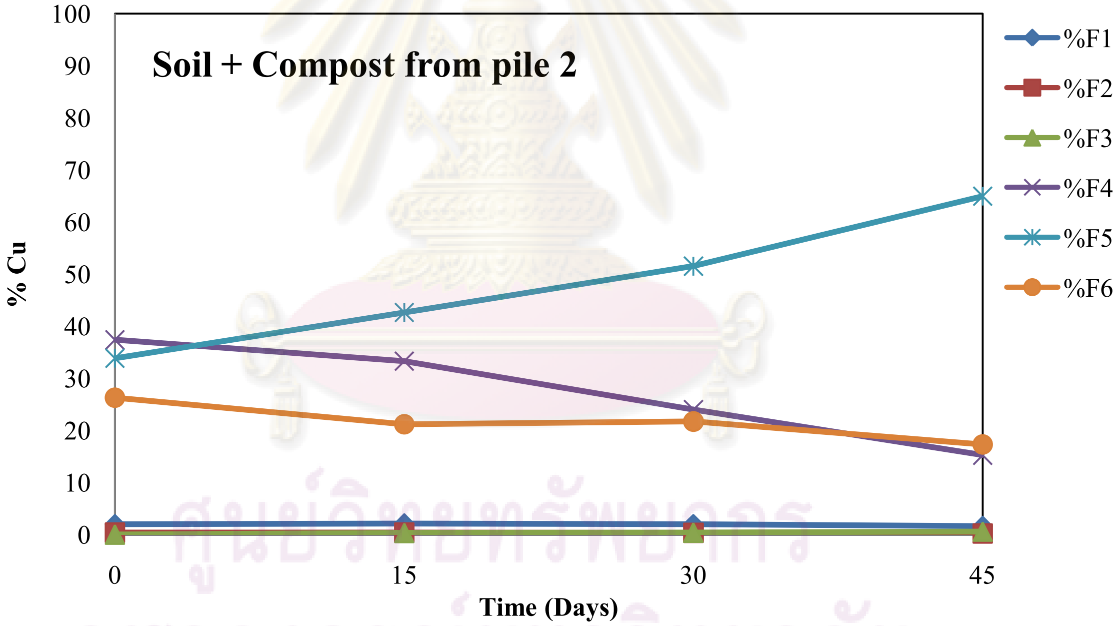
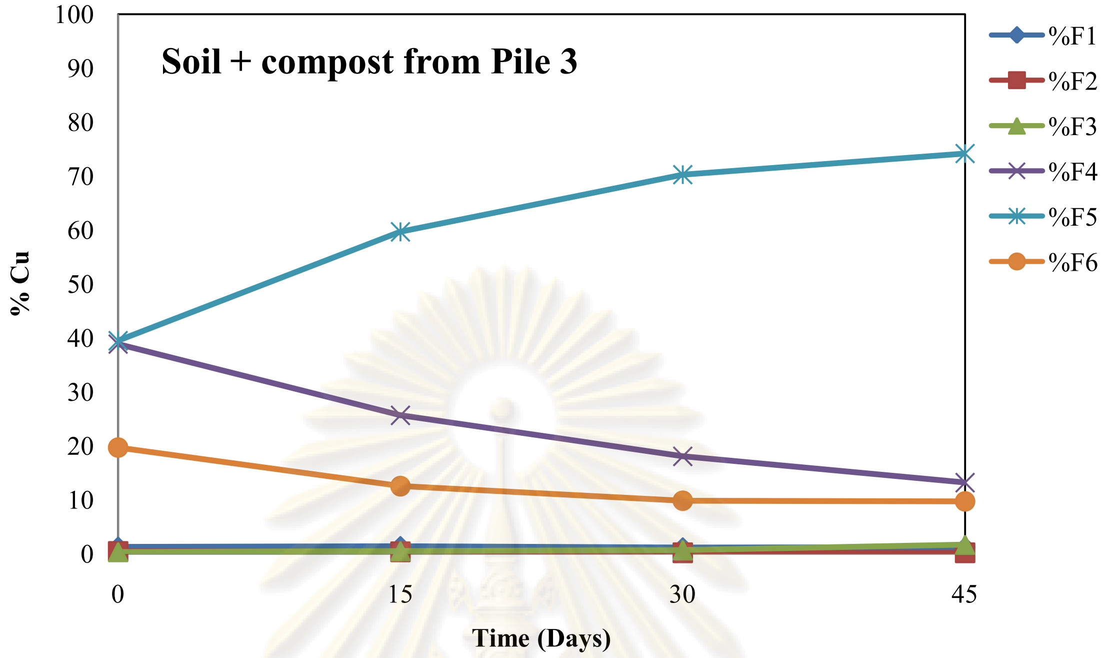


Figure 4.20 The six fractions of Cu in soil and soil amended with compost during 45 days of *Brassica campertris var. chinensis* planting



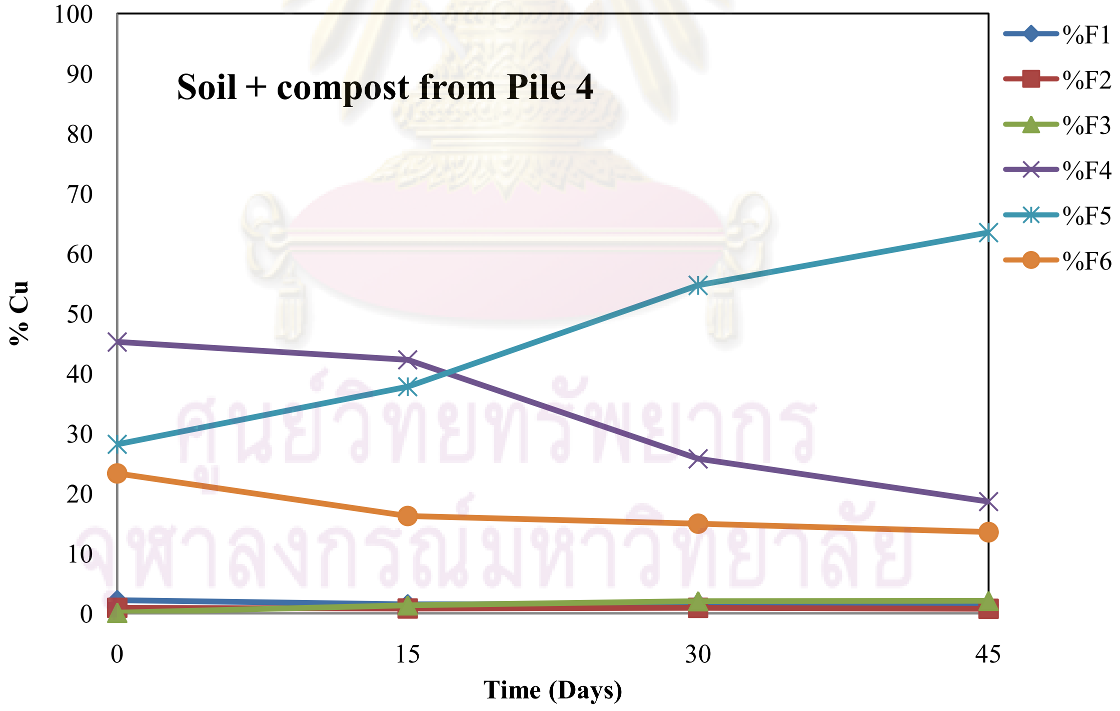


Figure 4.20 The six fractions of Cu in soil and soil amended with compost during 45 days of *Brassica campertris var. chinensis* planting (continued)

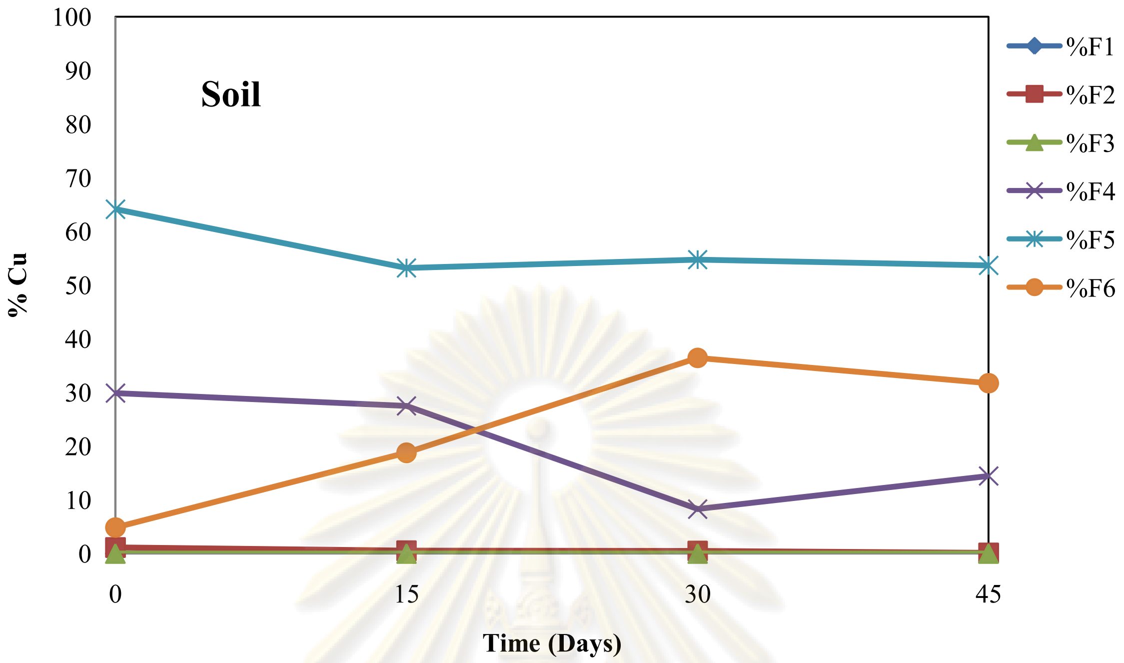


Figure 4.20 The six fractions of Cu in soil and soil amended with compost during 45 days of *Brassica campertris var. chinensis* planting (continued)

Like Cu-F4, the Cu-F6 represented the decreasing but slightly less than those found in F4. The different results were investigated in the soil control sample, which was not amended with compost. There was an increasing of the proportion of Cu-F6 while Cu-F4 and Cu-F5 decreased. The Cu-F4 in all soils and soil amended decreased with time and was redistributed to other fractions, which seemed to be more in the stable fraction during planting process. In this study, very high level of Cu was presented in the organic bound fraction, it was due to the fact that most minerals in soil was associated with high organic matter contain suitable reactive groups (hydroxyl, carboxyl, etc.) for the formation of complexes with Cu from compost compounds and Cu is preferentially retained on organic matter by complexation rather than by ion exchange. Wu *et al.*, (1999), who investigated the sorption of Cu on various clay and clay-organic matter fractions obtained from soils, and found that Cu was preferentially retained on organic matter. This result was similar to the partitioning and speciation of chromium, copper, and arsenic in CCA-contaminated soils studied by Balasoiu *et al.,* (2000). They found that Cu in CCA-contaminated soils were highly in organic bound fraction.

Considering to the pH variation in soils and soil amended during planting (Table 4.4), it was found that the soil control sample used in this study presented the acidity. The addition of this soil to compost, therefore, affected in the lowering of the pH in the pot test.

Table 4.4 The pH level in soil and soil amended during planting

Days	pH level				
	Soil	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**
0	5.60	6.70	7.00	6.80	6.60
15	6.67	6.45	7.18	7.02	6.78
30	5.89	6.61	6.51	6.60	6.55
45	5.98	6.7	6.78	6.61	6.71

The relative mobility, dependent on the pH of some trace elements in soil has been investigated by Fuller, 1997. He found that under the pH level of 6.7-8.8 (which was found in this study) the mobility of Cu was slow. Correspondence with the results obtained in this study, it was found that the Cu was mostly in the stable fraction than the mobile fraction.

4.2.1.3 Fractionations of chromium in soil and soils amended compost during planting process

The results of Cr in soil and soil amended composts during 45 days of planting process are shown in Figure 4.21 and Appendix B.

Similar to the Cu pattern, the variation of Cr exhibited during planting process showed that the variations of the Cr-F1, Cr-F2 and Cr-F3 proportion were trivial, compared with other fractions and their tendencies increased with time. After planting started, the Cr-F4 in all compost amended pots decreased with time and resemble to redistribute into the stable fraction while the Cr-F6 seemed to remain constantly. Most of the Cr in all pots existed in the organic bound fraction (F5) which represented the increase of 23.64%, 34.88%, 17.71% and 19.90% in soil amended with compost from pile1, pile2, pile 3, and pile4, respectively. In contrast, the presence of Cr in the soil control sample showed high proportion of Fe/Mn oxide bound. This probably due to that the Fe/Mn minerals which easily associated with Cr were dominated in the soil minerals composition. Chromium partitioning was similar to Cu, but presented some differences.

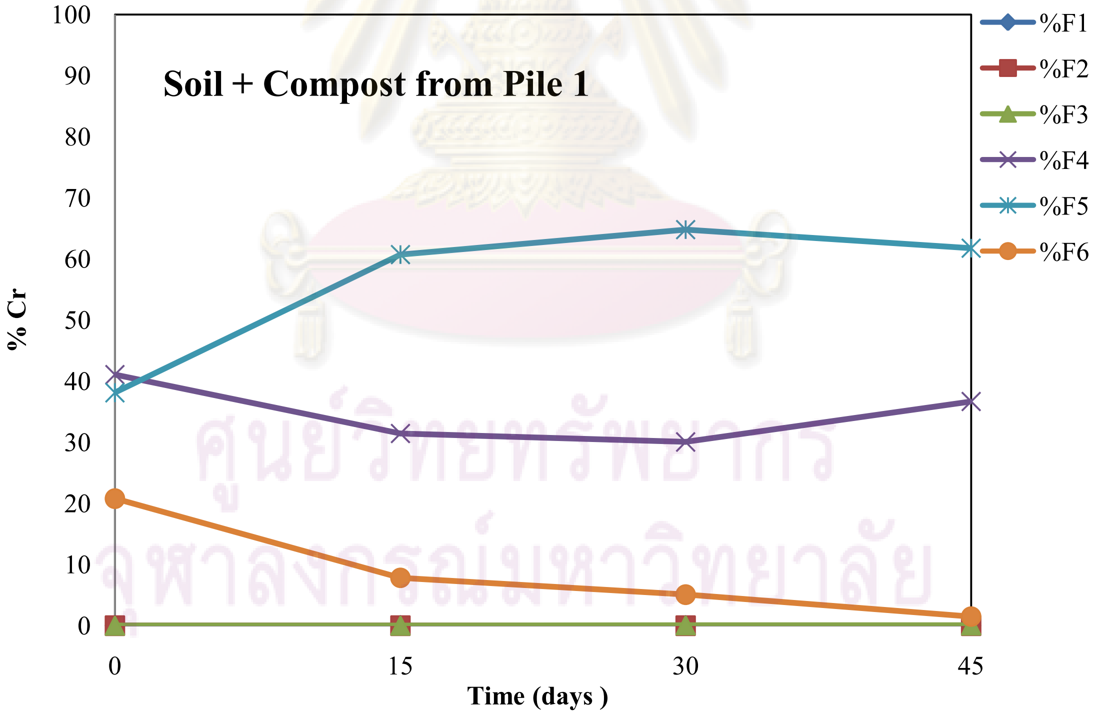
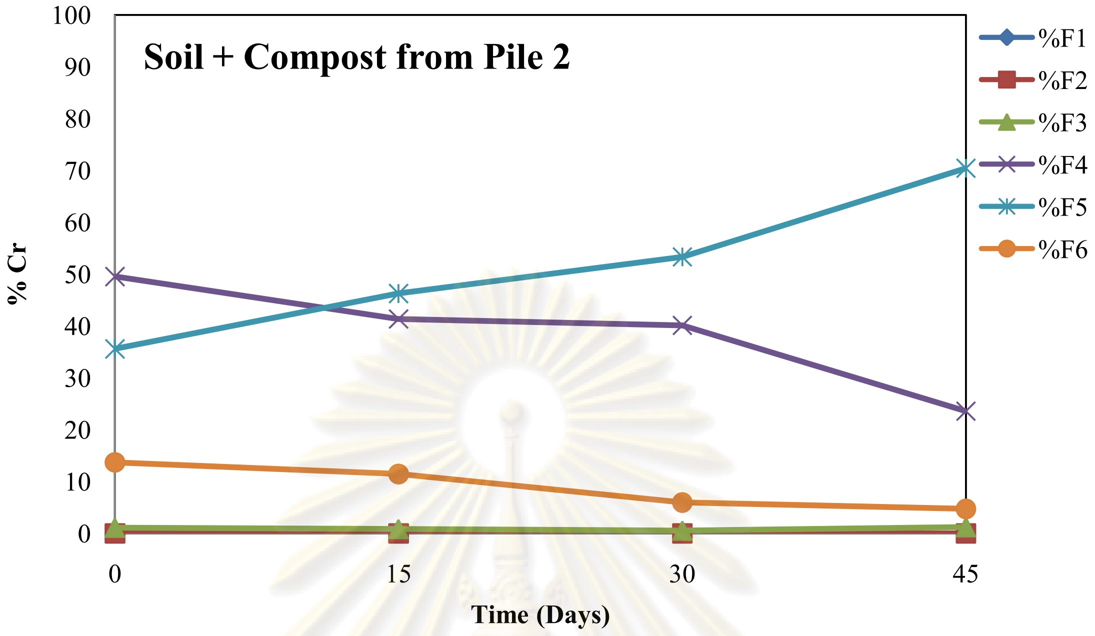


Figure 4.21 The six fractions of Cr in soil and soil amended with compost during 45 days of *Brassica campertris var. chinensis* planting



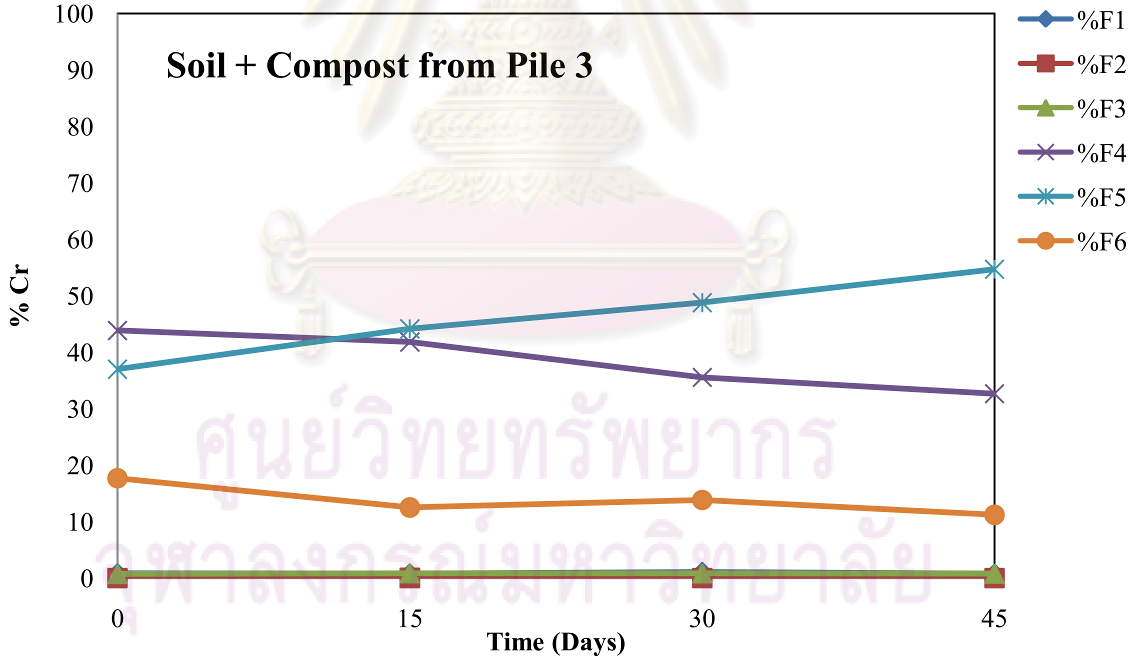


Figure 4.21 The six fractions of Cr in soil and soil amended with compost during 45 days of *Brassica campertris var. chinensis* planting (continued)

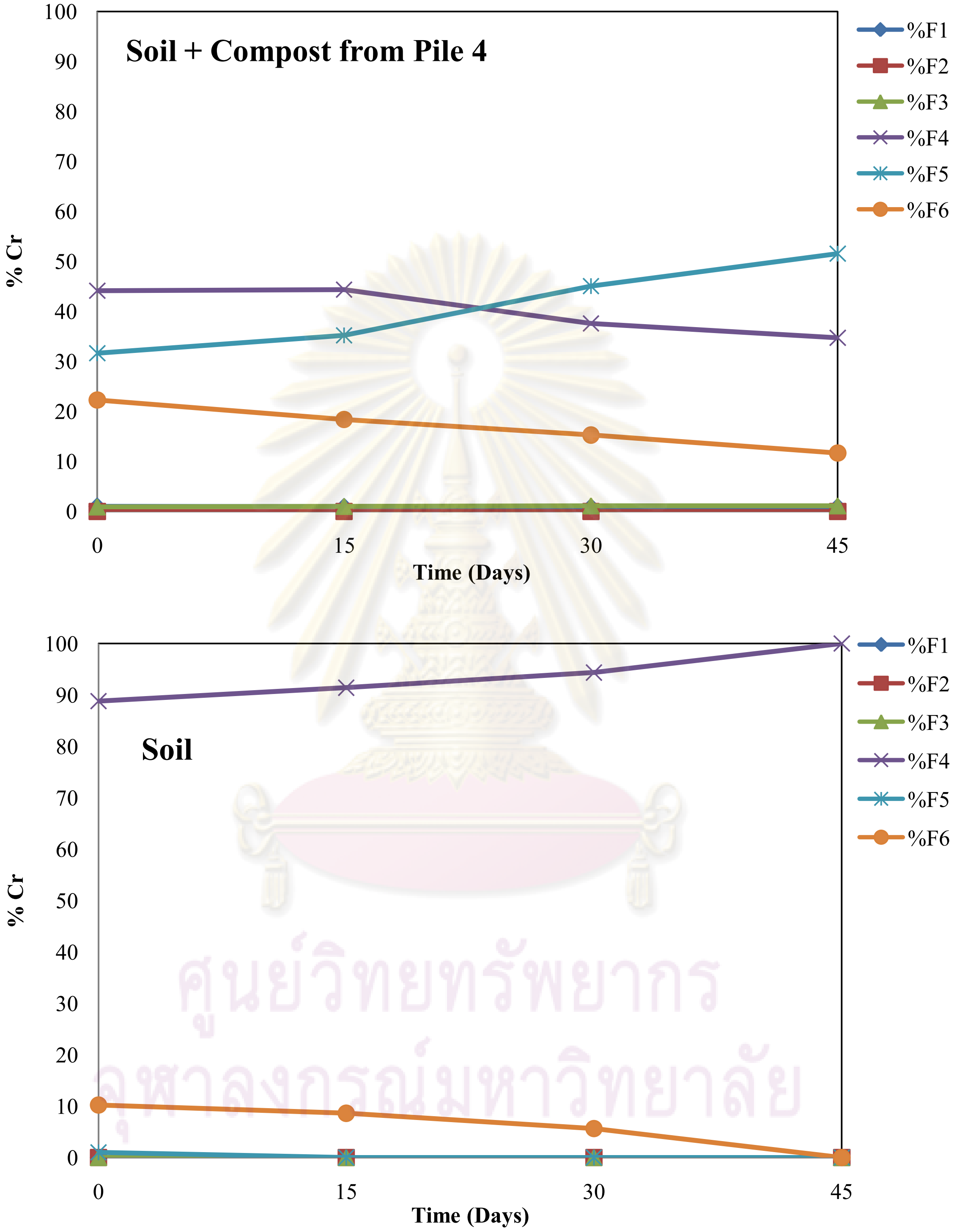


Figure 4.21 The six fractions of Cr in soil and soil amended with compost during 45 days of *Brassica campertris var. chinensis* planting (continued)

First of all, the level of Cr found in a reducible form (F4) in the four soils amended with compost were relatively higher than other fractions, suggesting that most of the chromium retained in the soils kept its original oxidation state at the initial of planting process. After that, reducing conditions from the soil are encountered into Cr contaminated compost, a mobilization of Cr could occur. The mobilizations of Cr during planting seemed to transform into the organic bound fraction (F5) rather than the residue fraction (F6). Likewise, the study of the fractionation of heavy metals in sandy and loessial soils, conducted by Han and Banin (1999) showed that, after the addition of the metal salts to the soil, Cr was mostly bound to the organic matter fraction.

4.2.1.4 Fractionations of Arsenic in soil and soils amended compost during planting process

The results of As in soil and soil amended composts during 45 days of planting process are shown in Figure 4.22 and Appendix B.

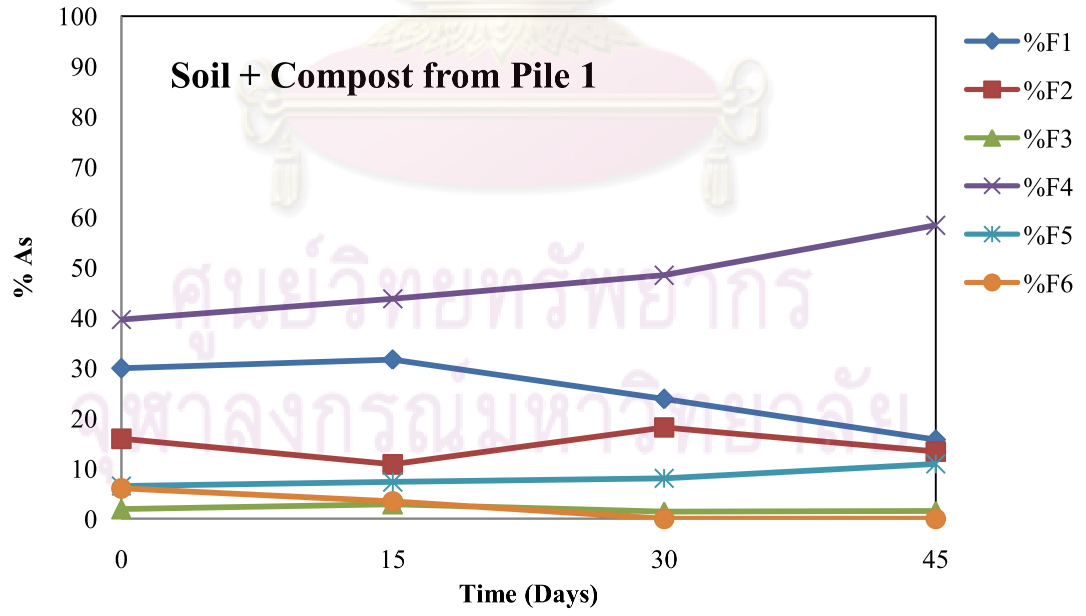
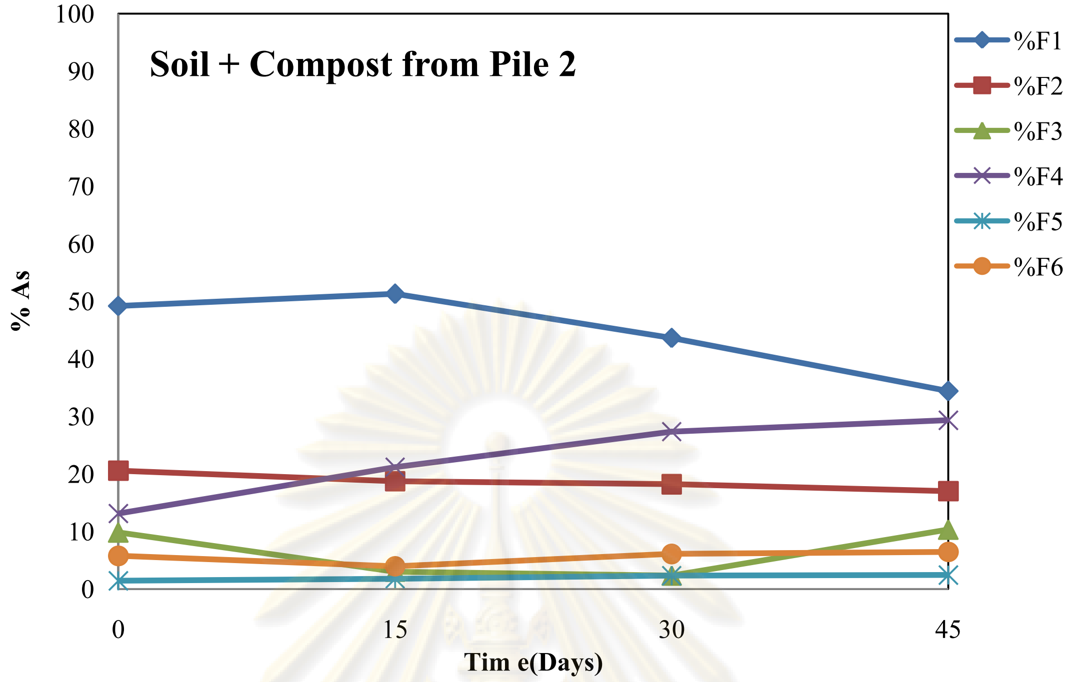


Figure 4.22 The six fractions of As in soil and soil amended with compost during 45 days of *Brassica campertris var. chinensis* planting



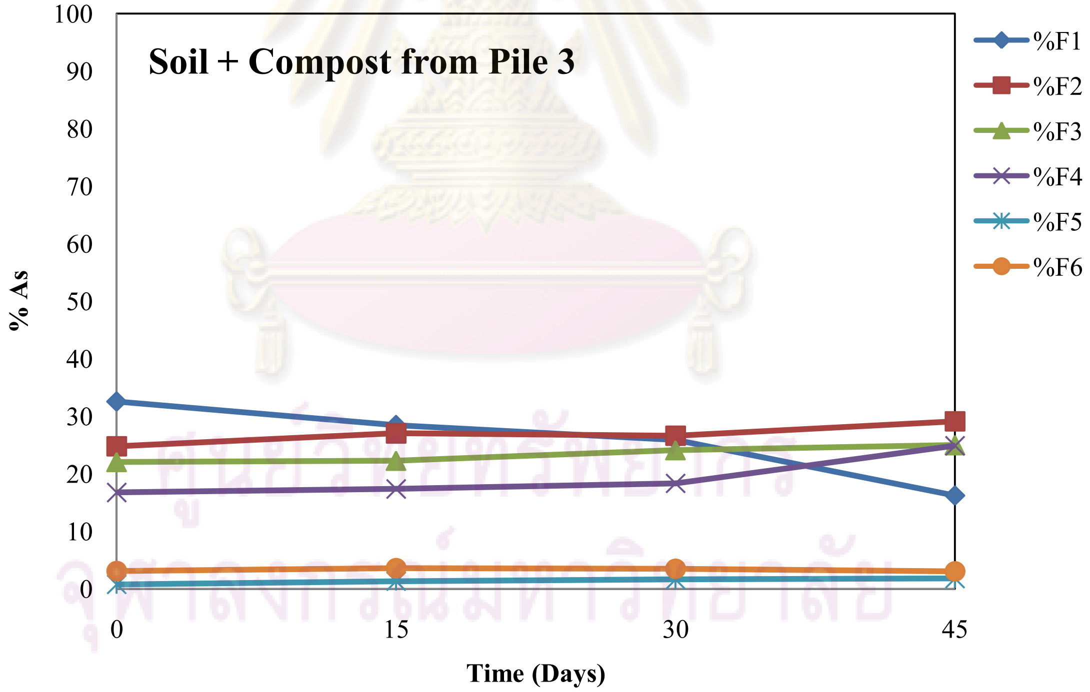
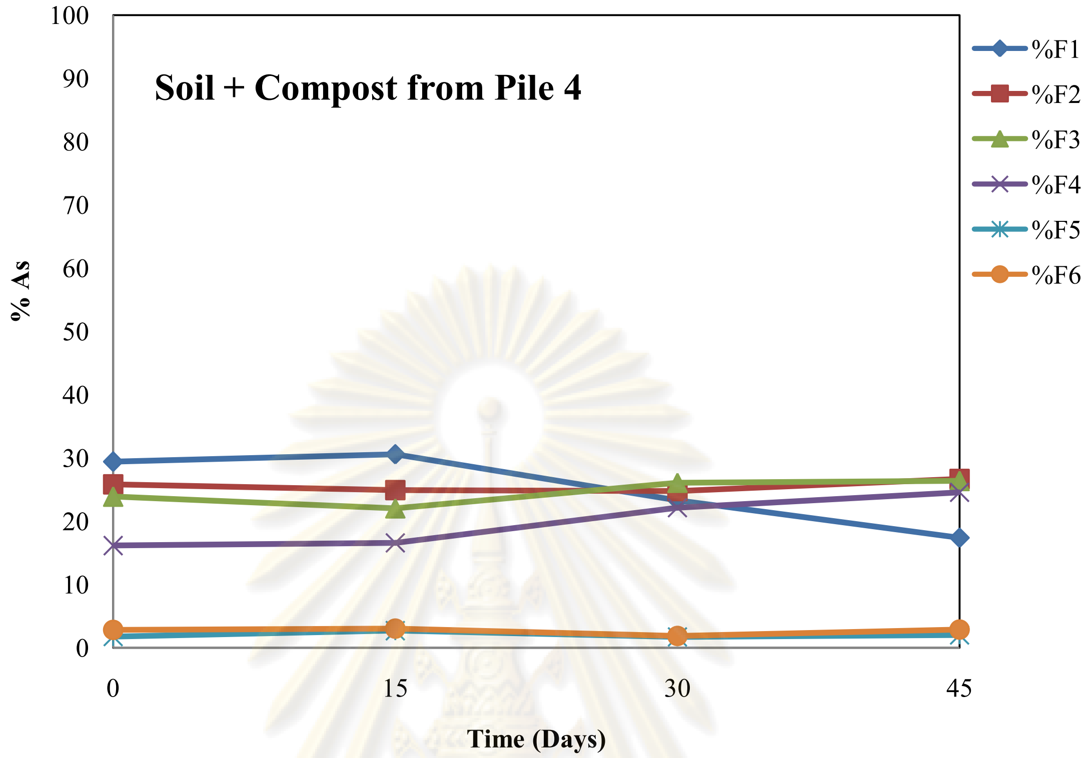


Figure 4.22 The six fractions of As in soil and soil amended with compost during 45 days of *Brassica campertris var. chinensis* planting (continued)



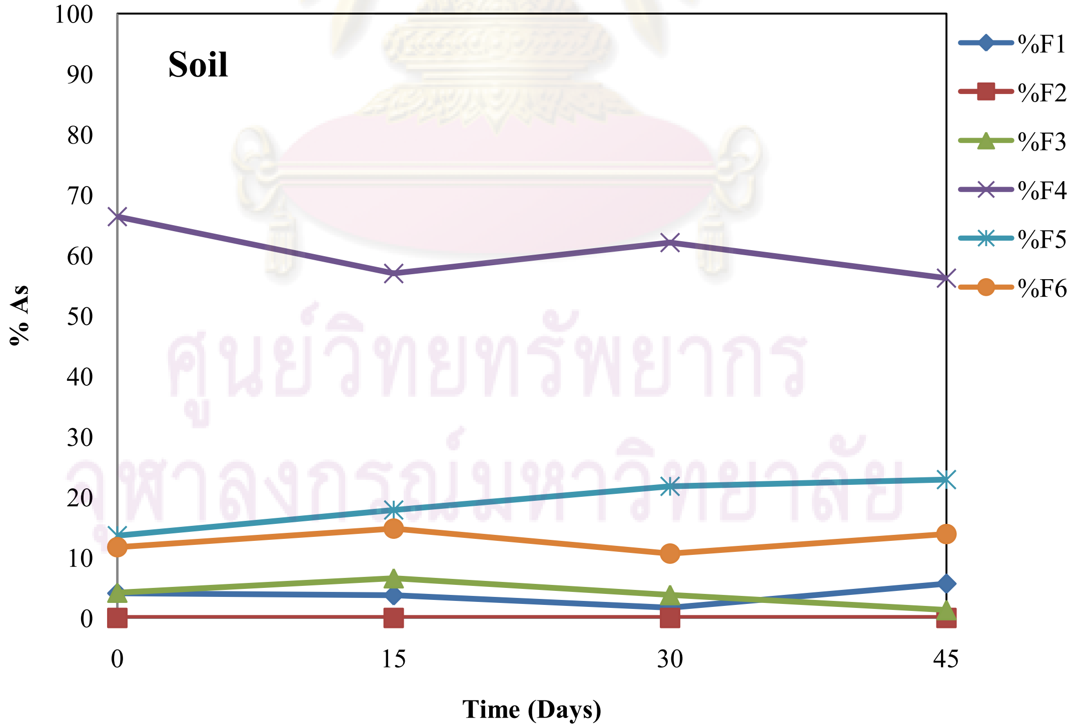


Figure 4.22 The six fractions of As in soil and soil amended with compost during 45 days of *Brassica campertris var. chinensis* planting (continued)

As shown in Figure 4.22, the proportions of As-F5 and As-F6, which were considered as the stable fractions, were obviously low in soil amended with compost. Most of As fractions were found in the mobile phase including of soluble, exchangeable, and Fe/Mn oxide bound metals, except carbonate bound fraction. In case of the carbonate bound fraction, it was found mainly in the soils amended with compost pile 3 and 4, but lower in the soil control and the soils amended with composts from pile 1 and 2. During planting process, the proportion of As-F2, As-F3 remained constant while the As-F4 increased. The As-F1 presents the gradually decreasing, in which its reductions were found to be 14.1%, 14.8%, 16.3%, and 12% in soil amended with compost in pile 1, 2, 3, and 4, respectively. These declines were possibly due to the plant uptake process because this form was easy to uptake by plant root. In addition, the arsenic has an affinity in mobile within the environment and may circulate many times in various forms through the atmosphere, water, and soil before entering its ultimate sink to sediment (Fishbein, 1988). Therefore, with no doubt, the arsenic presences in this study were rather associated with the metal mobile fraction than the immobile or the stable metal fraction. Similar to the Cr results found in the soil control sample, the highest proportion of As was distributed in As-F4, which is the reducible form. This probably due to the fact that the Fe/Mn minerals which easily associated with Cr and As were dominated in the soil minerals composition. In addition, adsorption-desorption on Fe oxide minerals is the main factor controlling arsenic behavior in soil and sediment (Leonard, 1991). Under the pH ranges in this study, it was found that the As which present under pH range around 6.7-8.8 was relatively mobile (Fuller, 1997).

In summary, in this study, the Cr and Cu were present in the less mobile and less available forms for soil organisms and plants whereas As was mainly in the mobile phase, in which considered as the bioavailable element.

4.2.2 Plant uptake of metals from soil and soil amended compost

4.2.2.1 Distributions of Cu in plant

Copper is one of several heavy metals that are both essential and toxic to animals and plants. Varying soil qualities influence the uptake of Cu by plants (Lepp, 1981). It is assumed that exchange reaction and the nitrogen content of the soil are important factors for the passive transport of Cu. The accumulation of Cu mostly found in root and its cell walls and is transported into above ground parts on various ways (Lepp, 1981). The results obtained in this study showed that, after 45 days of planting, the accumulation of Cu occurred in plants both in above-ground parts and root part. Table 4.5 showed the concentrations of Cu in both parts of plants while Table 4.6 showed the Cu fraction which presented in each part of plant.

Table 4.5 Concentrations of Cu in plant during 45 days of *Brassica campertris var. chinensis* planting

Type of soil	Concentrations of Cu (mg/kg)		Proportions of Cu (%)	
	Root	Above-ground	Root	Above-ground
Soil control	0.025	ND*	100	ND
Soil amended with compost from pile 1	0.475	0.006	98.75	1.25
Soil amended with compost from pile 2	4.350	0.225	95.05	4.95
Soil amended with compost from pile 3	9.075	0.795	91.95	8.05
Soil amended with compost from pile 4	13.45	3.55	79.12	20.88

*Not detectable

As shown in Table 4.5, most of Cu concentration in all types of soils presented in the plant roots (>80%) and the concentrations were highest in the soil amended with compost from pile 4. This could be due to that fact that the increasing of Cu concentration was influenced by the proportion of CCA-treated wood which presented in the compost amender. The results obtained from this study were corresponded to the above mentioned past research (Lepp, 1981) that the accumulation of Cu mostly found in the root of plant.

The results from one-way ANOVA test indicated that percentage of Cu present in root and above-ground parts in all soil type were significantly ($p< 0.05$) different. The percentages of Cu in root were significant higher than those above-ground parts.

Table 4.6 Fractionations of Cu in above-ground and root of plant after 45 days of *Brassica campertris var. chinensis* planting

Type of Soil	**Plants parts**	**Concentration of Cu (mg/kg)**					
		F1	**F2**	**F3**	**F4**	**F5**	**F6**
Soil control	Root	0.015	ND*	ND	ND	ND	0.01
	Above-ground	ND	ND	ND	ND	ND	ND
Soil amended with compost from pile 1	Root	0.454	ND	ND	0.020	ND	0.001
	Above-ground	0.006	ND	ND	ND	ND	ND
Soil amended with compost from pile 2	Root	3.811	ND	ND	0.012	ND	0.537
	Above-ground	0.220	0.005	ND	ND	ND	ND
Soil amended with compost from pile 3	Root	7.301	ND	ND	0.153	ND	1.621
	Above-ground	0.780	0.015	ND	ND	ND	ND
Soil amended with compost from pile 4	Root	10.35	ND	ND	0.534	ND	2.560
	Above-ground	3.453	0.097	ND	ND	ND	ND

*Not detectable

The fractionation of Cu in plants after 45 days of planting showed that Cu in plant mostly associated with the mobile fraction, especially in the water soluble fraction. The Cu-F3 and Cu-F5 were not present in plants, whereas Cu-F2 and Cu-F4 were present in only soil amended with compost. The metals found in plant were probably from the uptaking of the mobile metal from soil by plant. However, in comparison with the concentrations of Cu in soils (see Appendix B), the concentrations of Cu presented in plants were much less than those Cu presented in the soil and soil amended with composts.

4.2.2.2 Distributions of Cr in plant

The uptake of Cr from soil depends on the species of plants, and within a plant the concentrations largely differ between different parts of the plant (Sykes *et al.*, 1981). The quantities of Cr in the soil which are actually dangerous for the plants depend largely on its bioavailability for them. The results obtained in this study showed that, after 45 days of planting, the accumulation of Cr occurred in plants only in the root. Table 4.7 shows the concentrations of Cr in the roots. And Table 4.8 shows the Cr fraction presented in the roots. Similar to Cu, the Cr concentrations in the roots of plants raising with different portions of CCA-treated wood in the composts showed the increasing value according to the increasing amount of CCA-treated wood presented.

Table 4.7 Concentrations of Cr in plant during 45 days of *Brassica campertris var. chinensis* planting

Type of soil	**Concentrations of Cr in root (mg/kg)**
Soil control	0.075
Soil amended with compost from pile 1	0.150
Soil amended with compost from pile 2	0.895
Soil amended with compost from pile 3	3.761
Soil amended with compost from pile 4	10.06

Table 4.8 Fractionations of Cr in root of plant after 45 days of *Brassica campertris var. chinensis* planting

Type of Soil	Concentration of Cu (mg/kg)					
	F1	**F2**	**F3**	**F4**	**F5**	**F6**
Soil control	0.075	ND*	ND	ND	ND	ND
Soil amended with compost from pile 1	0.150	ND	ND	ND	ND	ND
Soil amended with compost from pile 2	0.895	ND	ND	ND	ND	ND
Soil amended with compost from pile 3	3.761	ND	ND	ND	ND	ND
Soil amended with compost from pile 4	10.06	ND	ND	ND	ND	ND

*Not detectable

The fractionation of Cr in plants after 45 days of planting showed that Cu in plant associated only in water soluble fraction. Other fractions were not detected in any part of plants. Like Cu, the metals found in plant were probably from the uptaking of the mobile metal from soils. However, in comparison with the concentration of Cr in soils (see Appendix B), the concentrations of Cr presented in plants were much less than those Cr presented in the soil and soil amended with compost.

In general, in spite of high Cr additions to the soil, only low concentrations of Cr were found in the edible parts of the plants. The translocation of Cr from the root through the plant to the leaves was rather low which might be because of the main barrier of its transportation into the vessel (Peterson and Girling, 1981).

4.2.2.3 Distributions of As in plant

The toxicity of arsenic to plants is primarily a function of the chemical form and oxidation state of the element. The phytotoxicity of As varies with the plant species, the soil As levels and soil characteristics, the type of compound and the temperature. Natural levels of As in vegetation rarely exceed 1-2 mg/kg on a dry weight basis but the content may be increased if the plant growing in contaminated soil, like soil contaminated with pesticide. Phytotoxicity of single As was well documented but little is known about their combined effects to plants when presented simultaneously in soil. The results obtained in this study showed that, after 45 days of planting, the accumulation of As occurred in both the root and the above-ground of the plant. Table 4.9 shows the concentrations of As in the plant while Table 4.10 shows the As fraction presented.

As shown in Table 4.9, most of As concentrations in all types of soil presented in the above-ground part (>70%). The variation of As concentrations were influenced by the proportion of CCA-treated wood which presented in the compost. As mentioned above, the phytotoxicity of As varies with the plant species, the soil As levels and soil characteristics. Leonard, 1986 indicated that natural arsenic levels in plants seldom exceed 1 mg/kg, but the leaf content may be higher if arsenic pesticides have been used. Moreover, it was reported that the uptake of arsenic by grasses, rush, reed, and nettle from the Rhine estuary and from water near mines showed the higher arsenic concentration in dead leaves than in roots (Otte *et al.*, 1988).

The fractionation of As in plants after 45 days of planting showed that As in plant mostly associated with the mobile fraction, especially in the water soluble fraction. Like Cu, the As-F3 and As-F5 were not present in plants, whereas As-F2 presented in only soil amended with compost. The metals found in plant were probably from 1) the releasing of mobile metal from soils under the changing of pH condition that mentioned in sector 4.2.1 above, and 2) the As itself was high affinity to the mobile fraction, therefore, the high proportion typically presented. However, in comparison with the concentration of As in soils (see Appendix B), the concentrations of As presented in plants were much less than those As presented in the soil and the soil amended with compost.

The results from one-way ANOVA test indicated that percentage of As presented in the root and above-ground parts in all soil types were significantly ($p < 0.05$) different. The percentages of As in the above-ground parts were significant higher than the roots.

Table 4.9 Concentrations of As in plant during 45 days of *Brassica campertris var. chinensis* planting

Type of soil	**Concentrations of As (mg/kg)**		**Proportions of As (%)**	
	Root	**Above-ground**	**Root**	**Above-ground**
Soil control	0.075	1.506	4.74	95.26
Soil amended with compost from pile 1	1.27	4.862	20.71	79.29
Soil amended with compost from pile 2	3.422	15.04	18.54	81.46
Soil amended with compost from pile 3	10.55	24.76	29.98	70.12
Soil amended with compost from pile 4	19.02	47.09	28.77	71.23

Table 4.10 Concentrations of As in each fractionation in above-ground root of plant after 45 days of *Brassica campertris var. chinensis* planting

Type of Soil	**Plants parts**	**Concentration of As (mg/kg)**					
		F1	**F2**	**F3**	**F4**	**F5**	**F6**
Soil control	Root	0.06	ND*	ND	ND	ND	0.015
	Above-ground	1.006	ND	ND	ND	ND	0.5
Soil amended with compost from pile 1	Root	1.030	ND	ND	ND	ND	0.240
	Above-ground	3.853	ND	ND	ND	ND	1.009

*Not detectable

Table 4.10 Concentrations of As in each fractionation in above-ground root of plant after 45 days of *Brassica campertris var. chinensis* planting (continued)

Type of Soil	**Plants parts**	**Concentration of As (mg/kg)**					
		F1	**F2**	**F3**	**F4**	**F5**	**F6**
Soil amended with compost from pile 2	Root	8.002	ND*	ND	ND	ND	2.546
	Above-ground	10.15	1.906	ND	ND	ND	2.894
Soil amended with compost from pile 3	Root	2.388	ND	ND	ND	ND	1.621
	Above-ground	18.22	4.253	ND	ND	ND	2.293
Soil amended with compost from pile 4	Root	14.42	ND	ND	ND	ND	4.601
	Above-ground	26.50	6.692	ND	ND	ND	3.909

*Not detectable

4.2.3 Growth of plants

Figure 4.23 illustrated the plants after 45 days of planting in the soil control and the soil amended with compost. It should be remarked that all plants in the pot with solely CCA-treated wood shaving died after planting for 15 days. The results showed that some plants died, especially in the pots with the soil control and the higher portion of CCA-treated wood in the compost. The results also showed that the lower plant growth was investigated in the soil control pot that no CCA-treated wood was mixed in the compost, compared with the soil amended compost pots from pile 1 and 2. It might be because of the plant nutrient in this soil was not enough for the plant’s need. It should be remarked that no fertilizer was added in the soil for planting. The soil amended compost had higher amount of nutrients due to the addition of chicken manure in the compost mix.

Soil control

Soil amended with compost from pile 1

Soil amended with compost from pile 2

Figure 4.23 The *Brassica campertris var. chinensis* growth after 45 days of planting

Soil amended with compost from pile 3

Soil amended with compost from pile 4

Figure 4.23 The *Brassica campertris var. chinensis* growth after 45 days of planting (Continued)

4.2.3.1 Fresh and dry weight of plant

During 45 days of *Brassica campertris var. chinensis* planting, the results of the average fresh and dry weights per stem of the plants showed in Appendix B and Figure 4.24 to 4.25.

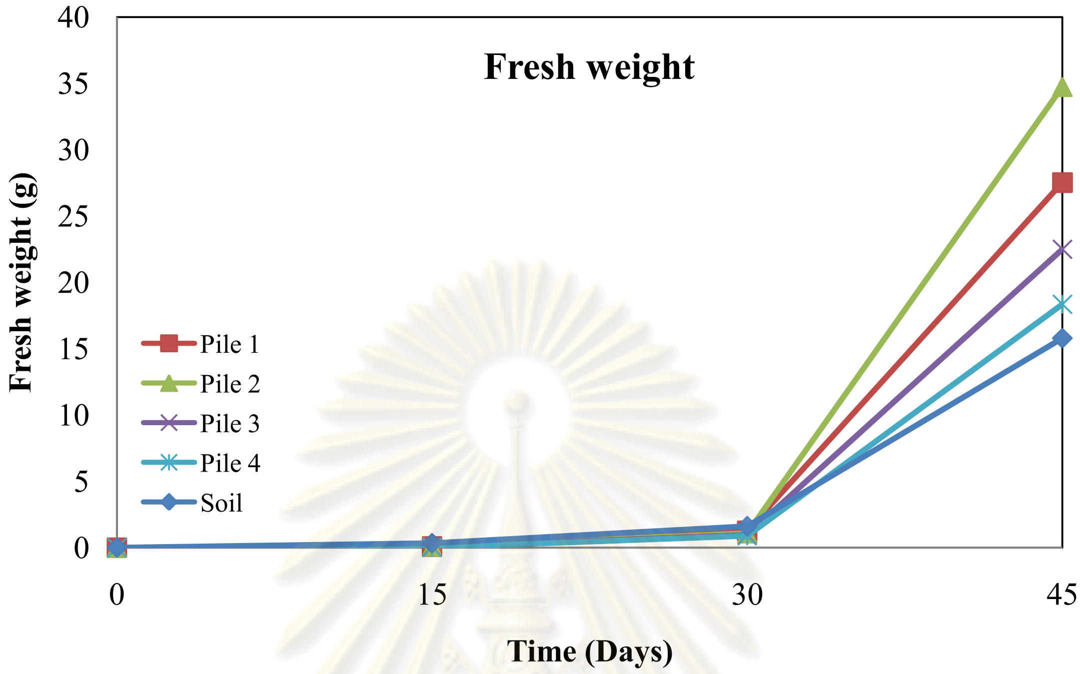


Figure 4.24 Fresh weight of *Brassica campertris var. chinensis* during 45 days of planting

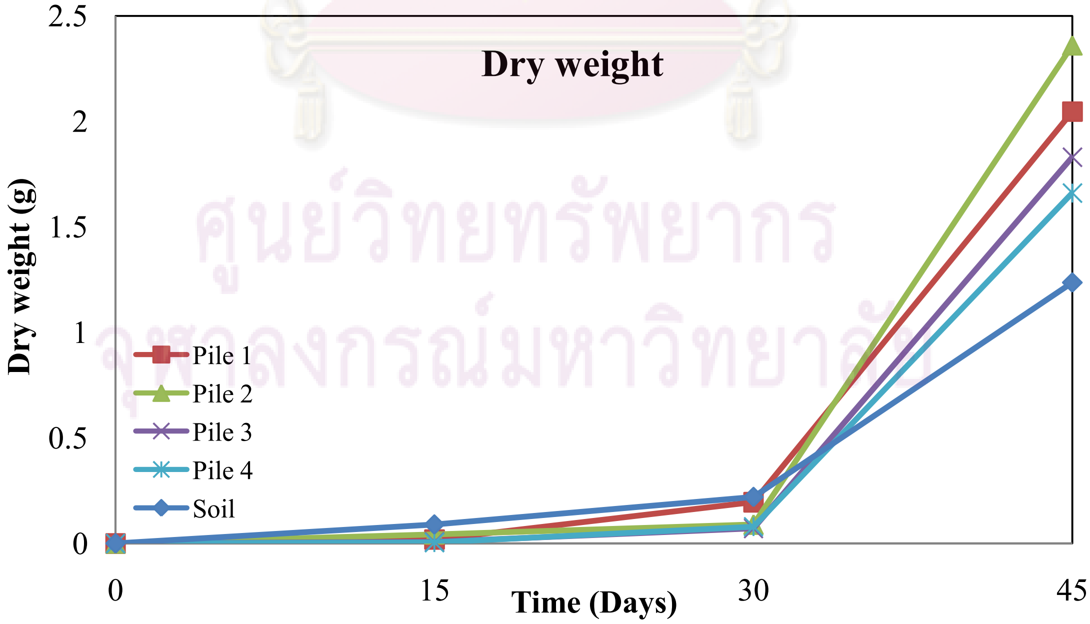


Figure 4.25 Dry weight of *Brassica campertris var. chinensis* during 45 days of planting

During 45 days of *Brassica campertris var. chinensis* planting, the results showed that their fresh and dry weights increased with time of planting. After harvesting, the average values of the fresh weight of *Brassica campertris var. chinensis* were 15.7, 27.52, 37.74, 22.49, and 18.34 g in soil control, soil amended with compost from pile 1, 2, 3, and 4, respectively. And the average values of the dry weight of *Brassica campertris var. chinensis* were 1.23, 2.04, 2.36, 1.83, and 1.66 g in soil control, soil amended with compost from pile 1, 2, 3, and 4, respectively.

As shown in Figure 4.23 and 4.24, it was found that the fresh and dry weights of *Brassica campertris var. chinensis* grown in the soil amended with compost from pile 2 was highest.

4.2.3.2 Length of roots, trunks and leaves

During 45 days of *Brassica campertris var. chinensis* planting, the results of the length of roots, trunks and leaves of the plants in Appendix B, Figure 4.26 to 4.28.

During 45 days of *Brassica campertris var. chinensis* planting, the results showed that the length of roots, trunks, and leaves of *Brassica campertris var. chinensis* grown in all soil types increased with time of planting. As shown in Figure 4.25, 4.26 and 4.27, it was found that the roots and leaves length values of *Brassica campertris var. chinensis* grown in the soil amended with compost from pile 2 was highest.

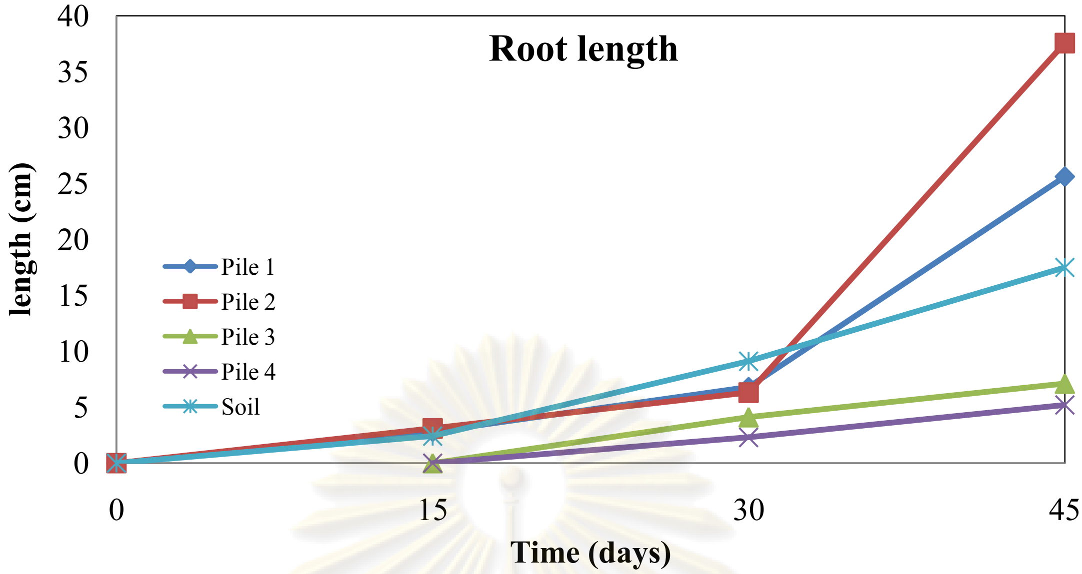


Figure 4.26 Root lengths of *Brassica campertris var. chinensis* during 45 days of planting

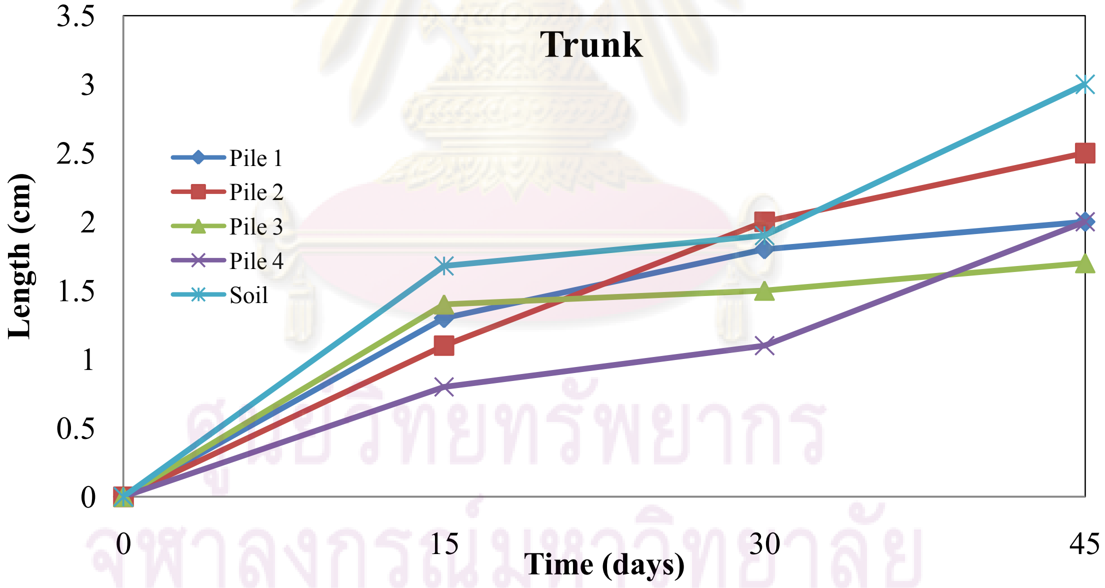


Figure 4.27 Trunks lengths of *Brassica campertris var. chinensis* during 45 days of planting

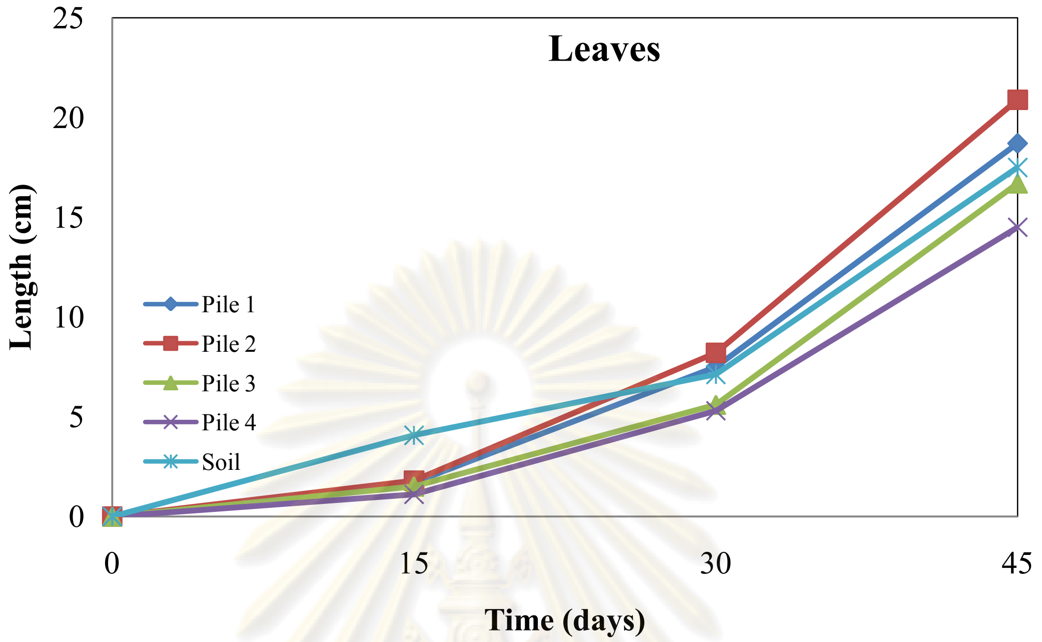


Figure 4.28 Leaves lengths of *Brassica campertris var. chinensis* during 45 days of planting

4.2.3.3 Percentage of plant growth

The effects of soil amended with compost on the plant growth were determined using pot test of *Brassica campertris var. chinensis.* The percentages of plants growth were calculated by using the following formula which developed from the formula used to determine the germination index in the experiment phase I.

$$Plant\ growth\ (\%) = \frac{\%\ \text{of plant grown in soil amended with compost pot x length of plant x 100}}{\%\ \text{of plant grown in soil control pot x length of plant in soil control pot}}$$

During 45 days of planting, the percentages of plant growth increased with time. The variations of percentage of the plant growth illustrates in Appendix B and Figure 4.29.

As illustrated in Figure 4.29, the percentages of plant growth increased with time of planting. The plant grown in the soil amended with compost from pile 2 reached the highest values whereas the lowest value was found in the soil amended with compost from pile 4. It can be indicated that the percentages of plant growth could be affected by the presence of CCA-treated wood only in high proportions.

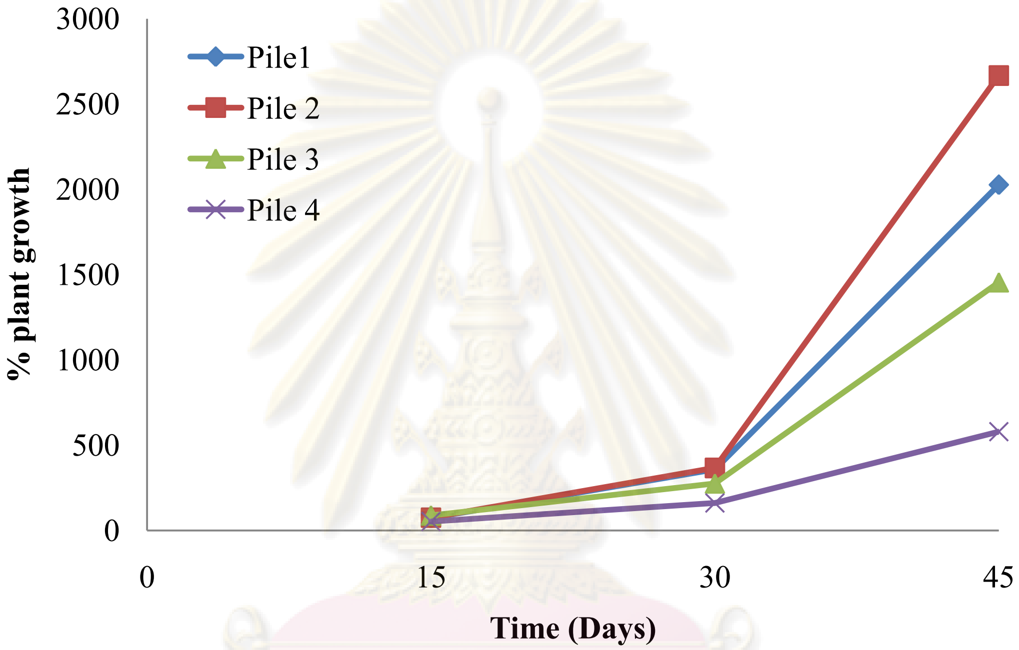


Figure 4.29 The percentage of *Brassica campertris var. chinensis* growth during 45 days

4.2.4 Heavy metal mass balance during planting

The masses of Cu, Cr and As at the day 0 and 45th of planting are shown in Table 4.11 to 4.17. The results clearly showed that after planting of *Brassica campertris var. chinensis* for 45 days, only small portions of all three metals were uptaken by plants.

Table 4.11 The results of mass balance of Cu, Cr and As at day 0 of planting process

Type of soil	Metals	Concentration of soil (mg/kg)	Mass of soil (kg.dry wt)	Mass of metals in soil
Soil control	**Cu**	17.00	2.69	*45.73*
	Cr	22.00	2.69	*59.23*
	As	11.35	2.69	*30.57*
Pile 1	**Cu**	49.01	1.64	*81.69*
	Cr	44.55	1.64	*73.45*
	As	35.65	1.64	*58.79*
Pile 2	**Cu**	340.0	1.64	*559.1*
	Cr	600.3	1.64	*987.2*
	As	247.4	1.64	*406.9*
Pile 3	**Cu**	901.7	1.60	*1447*
	Cr	1700	1.60	*2730*
	As	557.0	1.60	*894.3*
Pile 4	**Cu**	1447	1.63	*2364*
	Cr	2130	1.63	*3481*
	As	700.3	1.63	*1144*

Table 4.12 The results of mass balance of Cu, Cr and As at day 45th of planting process in soil.

	Concentration (mg/kg)			**Mass (kg.dry wt)**			**Mass of metals**			
	Soil	**Plant**		**Soil**	**Plant***		**Soil**	**Plant***		**Total**
		Root	**Above-ground**		**Root ($x10^{-4}$)**	**Above-ground ($x10^{-4}$)**		**Root ($x10^{-4}$)**	**Above-ground**	
Cu	15.3	0.03	ND	2.58	4.1	8.2	39.47	0.1	-	*39.47*
Cr	30.3	0.08	ND	2.58	4.1	8.2	78.24	0.3	-	*78.24*
As	15.5	0.08	1.51	2.58	4.1	8.2	40.13	0.3	0.00124	*40.13*

* Dry weight ratio of root part to above-ground part was 1 to 3

Table 4.13 The results of mass balance of Cu, Cr and As at day 45th of planting process in soil amended with compost from pile 1.

	Concentration (mg/kg)			**Mass (kg.dry wt)**			**Mass of metals**			
	Soil	**Plant**		**Soil**	**Plant***		**Soil**	**Plant***		**Total**
		Root	**Above-ground**		**Root ($x10^{-4}$)**	**Above-ground ($x10^{-4}$)**		**Root ($x10^{-4}$)**	**Above-ground**	
Cu	48.1	0.48	0.01	1.56	4.1	8.2	75.1	2	-	*75.1*
Cr	43.0	0.15	ND	1.56	4.1	8.2	67.15	0.6	-	*67.15*
As	29.0	1.27	4.86	1.56	4.1	8.2	45.31	5.2	0.00401	*45.31*

* Dry weight ratio of root part to above-ground part was 1 to 3

Table 4.14 The results of mass balance of Cu, Cr and As at day 45th of planting process in soil amended with compost from pile 2.

	Concentration (mg/kg)			**Mass (kg.dry wt)**			**Mass of metals**			
	Soil	**Plant**		**Soil**	**Plant***		**Soil**	**Plant***		**Total**
		Root	**Above-ground**		**Root ($x10^{-4}$)**	**Above-ground ($x10^{-4}$)**		**Root ($x10^{-4}$)**	**Above-ground**	
Cu	325	4.35	0.23	1.59	4.1	8.2	518.1	17.9	0.00019	*518.1*
Cr	595	0.90	ND	1.59	4.1	8.2	946	3.7	-	*946*
As	241	3.42	15	1.59	4.1	8.2	384.7	14.1	0.01239	*384.7*

* Dry weight ratio of root part to above-ground part was 1 to 3

Table 4.15 The results of mass balance of Cu, Cr and As at day 45th of planting process in soil amended with compost from pile 3.

	Concentration (mg/kg)			**Mass (kg.dry wt)**			**Mass of metals**			
	Soil	**Plant**		**Soil**	**Plant***		**Soil**	**Plant***		**Total**
		Root	**Above-ground**		**Root (x10^{-4})**	**Above-ground (x10^{-4})**		**Root (x10^{-4})**	**Above-ground**	
Cu	857	9.08	0.8	1.50	4.1	8.2	1286	37.4	0.00066	*1286*
Cr	1612	3.76	ND	1.50	4.1	8.2	2419	15.5	-	*2419*
As	546	10.5	24.7	1.50	4.1	8.2	819	43.6	0.0204	*819*

* Dry weight ratio of root part to above-ground part was 1 to 3

Table 4.16 The results of mass balance of Cu, Cr and As at day 45th of planting process in soil amended with compost from pile 4.

	Concentration (mg/kg)			**Mass (kg.dry wt)**			**Mass of metals**			
	Soil	**Plant**		**Soil**	**Plant***		**Soil**	**Plant***		**Total**
		Root	**Above-ground**		**Root (x10^{-4})**	**Above-ground (x10^{-4})**		**Root (x10^{-4})**	**Above-ground**	
Cu	1370	13.4	3.55	1.55	4.1	8.2	2123	55.4	0.00293	*2123*
Cr	2170	10.0	ND	1.55	4.1	8.2	3365	41.5	-	*3365*
As	679	19.1	47.1	1.55	4.1	8.2	1052	79.1	0.03881	*1052*

* Dry weight ratio of root part to above-ground part was 1 to 3

Table 4.17 The summary of mass balance of Cu, Cr and As at day 0 and 45th of planting process

Type of soil	**Metals**	**Mass of metals**	
		Initial (day 0)	**Final (day 45th)**
Soil control	**Cu**	45.73	39.47
	Cr	59.23	78.23
	As	30.57	40.13
Pile 1	**Cu**	81.69	75.10
	Cr	73.44	67.14
	As	58.79	45.31
Pile 2	**Cu**	559.1	518.1
	Cr	987.2	946.0
	As	406.9	384.7
Pile 3	**Cu**	1447	1286
	Cr	2730	2419
	As	894.3	819.0
Pile 4	**Cu**	2364	2123
	Cr	3481	3365
	As	1144	1052

CHAPTER V

CONCLUSIONS

The conclusions drawn from the study of aerobic composting process of CCA treated wood and chicken manure were summarized as followings:

1. The results of characterization of compost showed that the microorganisms could degrade the organic matter in all compost piles even for the highest proportion of CCA-treated wood in the compost mixture. No significant differences of the temperature, pH, moisture content, TVS, total organic carbon, TN, C/N and mass reduction values of all four piles were investigated.

2. The results of germination index values of all four piles show significant differences among the four compost piles. During composting, the pile with less proportion of CCA-treated wood had the significantly higher GI, compared with the pile with higher proportion of CCA-treated wood. As result of this, it could be indicated that the heavy metals consisting in the CCA-treated wood had an effect on the phytotoxicity during the composting process.

3. The total concentrations of Cu, Cr and As increased with time of composting due to the weight loss resulted from organic matter decomposition.

4. The results of the sequential extraction showed that during the composting process, As was mainly redistributed into the mobile fraction, whereas Cu and Cr had an affinity to the stable fraction. Therefore, it could be concluded that the application of the CCA treated wood compost should be of concern. Because of As shows the affinity to the mobile phase, which is able to

transform easily and may be accumulate and/or contaminated in soil and plants.

5. The results of the total Cu, Cr and As concentrations during the 45 days of *Brassica campertris var. chinensis* planting showed that the total concentrations of Cu, Cr, and As in all soils types slightly decreased with time. The sequential extraction analysis of soil amended with compost indicated that the Cr and Cu were present in the less mobile and less available forms for soil organisms and plants whereas As was mainly in the mobile phase, in which considered as the bioavailable element.

6. The fractionation of Cu, Cr, and As in plants after 45 days of *Brassica campertris var. chinensis* planting showed that Cu in plant mostly associated with the mobile fraction, especially in the water soluble fraction. The proportions of Cu and Cr mostly accumulated in the roots. In contrary, the percentages of As in the above-ground parts were significant higher than the roots.

7. In comparison with the concentrations of Cu, Cr, and As in soils, it was found that the concentrations of Cu, Cr, and As presented in plants were much less than those Cu presented in the soil and soil amended with composts.

8. The results of plant growth showed that the plant could grow in the soil amended compost containing low proportion of CCA-treated wood without any phytotoxicity effect.

9. In summary, the application of aerobic composting of CCA-treated wood amended with the chicken manure could be both lessen the bioavailability of Cu and Cr and reduced wastes volume. However, the application should be of concern about the leachate from compost because of the As mobilization.

10. In order to manage the CCA treated wood wastes which lessen the environment deteriorates effected by using the aerobic composting process, the researcher suggested the methods as followings :

    - The optimum ratio of wood shaving from CCA-treated wood and untreated wood is 1:2 (w/w)
    - The composting unit used is approximately 1 m^3 in size.
    - The initial C/N ratio is 25
    - The moisture content should be control in range of 55-60%
    - Using the chicken manure as the nitrogen supplier
    - Using the mature of household organic waste compost as the microbial supplier (adding about 5% of each compost mixture weight)
    - In order to use the compost to amend with soil for growing plant (*Brassica campertris var. chinensis*), the optimum ratio of mature compost and soil is 1:2 (v/v).

From the following method, the plant could grow without any phytotoxic and enhance plant growth as well.

CHAPTER VI

RECOMMENDATION FOR FUTURE WORKS

1. For future work, the experimental study on other types of chemically treated wood, such as painted wood, mixed composite panel products and plywood with concrete mould oils, should be carried out.

2. In order to confirm the uptake of the Cu, Cr and As by plants, the different species of plants should be conducted on the soils amended with the CCA compost.

3. The compost unit should be equipped with the leachate collecting part because the results of the study were found that the As had an affinity to water and more associated with the mobile phase rather than the stable phase. Therefore, the leachate from compost should be kept and manage in proper way.

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Appendices

APPENDIX A

CALCULATION THE PROPORTION OF CHICKEN MANURE AND WOOD SHAVING IN EACH PILE

The calculation methods for calculating optimum proportion of chicken manure and wood shaving in each compost piles.

The results of C/N ratios and moisture contents of chicken manure and wood shaving are shown on Table A-1.

Table A-1 The results of C/N ratios and contents of chicken manure and wood shaving

Composting materials	Carbon (% dry wt.)	Nitrogen (% dry wt.)	C/N ratio	Moisture content %
Wood shaving	62.24	0.46	135.30	30.83
Chicken manure	26.34	4.18	6.30	25.44

In order to control the initial C/N ratio of compost pile to be around 25, the quantity of compost materials used were calculated using the results from Table A-1. The calculation details show as following:

From results of carbon and nitrogen above:

Wood shaving 100 kg (dry wt.) consists of C = 62.24 kg and N = 0.46 kg

Wood shaving 1 kg (dry wt.) consists of C = 62.24/100 = 0.6224 kg and N = 0.46/100 = 0.0046 kg

How many of chicken manure need to add in the mixture?
(If using wood shaving = 1 kg (dry wt.))

Chicken manure 100 kg (dry wt.) consists of C = 26.34 kg and N = 4.18 kg

X = amount of chicken manure which need to mix with wood shaving

Chicken manure X kg (dry wt.) consists of C= 0.2734X kg and N = 0.418X kg

In order to balance the C/N ratio = 25

$$(C_{\text{wood shaving}} + C_{\text{chicken manure}})/\ (N_{\text{wood shaving}} + N_{\text{chicken manure}}) = 25$$

$$(0.6224 + 0.2634X)/(0.0046 + 0.0418X) = 25$$

$$X = 0.65$$

Therefore, the proportions of wood shaving per chicken manure = 1:0.65 (dry wt.)

In order to calculate the wet weight ratio,

The moisture contents of wood shaving and chicken manure were 30.83% 25.44%, respectively (Table A-1) and the ratio of wood shaving and chicken manure was 1:0.65 (dry wt.).

Therefore, wood shaving used = 100 / (100-30.83) = 1.44 kg (wet weight)
Chicken manure = 100 x 0.65/ (100-25.44) = 0.87 kg (wet weight)

APPENDIX B

EXPERIMENTAL DATA

Table B-1 The results of temperature during composting process

Time (Days)	Temperature				
	Room	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**
0	28.0	30.0	29.0	29.0	30.0
1	28.0	58.1	57.7	58.6	57.5
2	27.3	59.2	58.9	59.3	58.8
3	26.7	59.9	60.1	59.7	60.0
4	28.0	57.5	57.3	58.0	58.6
5	27.5	55.9	53.7	56.5	54.5
6	25.2	55.0	55.6	57.1	55.9
7	25.4	54.6	53.9	55.9	53.2
8	24.1	54.8	53.5	54.1	52.9
9	25.7	53.4	52.3	53.9	51.1
10	25.7	50.1	48.1	50.7	49.2
11	26.2	51.1	49.1	51.9	51.0
12	25.1	49.1	47.9	49.0	51.9
13	27.6	48.0	46.8	48.9	51.4
14	25.3	46.2	44.6	46.5	50.0
15	26.8	42.7	40.2	43.3	46.5
16	25.7	44.7	42.0	45.4	48.1
17	25.7	46.7	45.8	46.4	48.1
18	25.4	47.9	45.8	47.5	48.4
19	26.0	48.4	45.8	48.1	48.4
20	26.5	49.8	45.1	48.5	48.9
21	27.5	50.5	45.0	48.6	48.9
22	27.3	49.0	45.5	48.2	50.8
23	28.4	50.9	46.5	48.6	49.5
24	27.5	50.4	46.3	48.4	49.0
25	25.8	49.1	47.7	50.1	48.5
26	25.6	49.1	46.6	50.4	46.0
27	25.6	49.2	46.7	50.4	46.2
28	25.5	49.4	46.8	51.2	46.3
29	26.2	46.2	42.0	43.9	44.9
30	28.2	50.1	44.9	47.7	48.9
31	25.8	50.6	45.0	48.3	50.3
32	25.6	50.8	45.2	48.7	50.9
33	24.0	50.4	45.0	48.4	50.9
34	27.0	51.0	45.0	47.5	50.5
35	27.5	51.0	44.4	48.2	49.7
36	25.6	50.1	42.8	47.6	46.3
37	27.7	49.0	42.9	45.3	42.7
38	24.4	48.6	41.5	44.5	41.2
39	24.6	47.4	40.7	43.3	39.3
40	26.8	46.6	39.4	41.2	38.4
41	26.0	45.7	39.2	40.1	38.0
42	25.9	44.9	38.1	37.0	37.5
43	26.5	38.5	36.2	41.4	36.4
44	24.7	40.9	38.8	40.3	39.0
45	29.3	41.7	39.4	41.9	41.1

Table B-1(continued) The results of temperature during composting process

Time (Days)	Temperature				
	Room	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**
46	29.1	42.8	40.5	44.6	42.0
47	27.7	43.5	41.7	45.9	43.4
48	26.3	43.3	42.4	45.8	42.9
49	26.9	43.2	42.1	45.8	42.4
50	27.3	43.0	41.3	44.3	42.0
51	27.5	42.6	41.7	43.5	41.9
52	27.9	41.5	41.8	41.7	40.0
53	28.0	39.8	39.7	40.5	39.5
54	24.4	39.5	39.0	39.5	38.2
55	26.7	38.9	38.5	39.0	37.9
56	27.6	37.8	38.1	38.7	37.5
57	25.9	37.3	38.0	38.6	37.2
58	28.8	35.9	34.5	36.6	34.8
59	26.4	37.1	35.7	37.2	36.9
60	28.9	37.2	35.1	38.7	37.2
61	27.7	36.7	35.5	38.2	37.5
62	27.3	36.6	35.4	38.3	37.3
63	27.5	36.5	35.3	38.6	37.1
64	28.0	36.5	35.2	38.5	37.0
65	26.3	35.0	35.2	38.7	37.1
66	25.9	35.2	35.2	38.5	37.5
67	25.7	35.0	34.9	37.9	36.6
68	25.6	34.4	34.7	37.5	35.8
69	26.6	33.3	33.9	36.0	35.7
70	26.8	33.1	33.5	35.8	35.4
71	27.0	32.7	32.9	35.7	33.7
72	27.1	32.6	32.7	35.7	33.6
73	26.2	32.6	32.5	35.6	33.4
74	26.3	32.5	31.7	35.6	33.3
75	25.5	32.3	31.5	35.3	33.0
76	24.9	32.3	31.4	35.4	32.6
77	25.1	32.4	31.6	35.2	32.3
78	25.1	32.5	31.6	34.9	32.5
79	26.7	32.3	30.1	34.4	31.8
80	26.3	31.9	29.8	33.5	33.0
81	28.9	31.4	29.5	33.0	30.2
82	28.7	31.5	29.7	33.2	30.3
83	28.0	31.2	29.7	33.3	30.1
84	26.4	31.3	29.6	33.1	30.0
85	27.6	29.8	28.6	32.3	29.0
86	27.4	32.7	30.9	33.5	30.3
87	27.7	32.8	31.1	33.7	30.4
88	26.5	32.5	30.7	33.4	30.1
89	27.4	32.5	30.6	33.3	30.1
90	27.5	32.4	30.5	33.2	30.0
91	27.6	32.3	30.6	33.3	29.8
92	27.5	31.1	29.5	32.4	28.7

Table B-1(continued) The results of temperature during composting process

Time (Days)	Temperature				
	Room	Pile 1	Pile 2	Pile 3	Pile 4
93	26.4	32.3	30.6	33.1	29.9
94	26.7	32.2	30.5	32.9	30.0
95	26.8	32.0	30.2	32.7	30.1
96	26.2	31.9	30.1	32.2	29.8
97	27.0	31.8	30.0	32.3	30.0
98	27.5	31.8	30.1	31.4	30.2
99	26.5	31.0	29.5	30.9	28.9
100	26.3	32.0	30.3	31.7	30.4
101	26.0	31.7	29.1	31.7	29.8
102	26.1	31.5	28.6	31.3	29.4
103	25.7	31.3	28.7	31.2	29.5
104	25.8	31.1	28.5	30.8	29.1
105	25.1	30.9	28.1	30.5	28.7
106	25.8	30.5	27.9	30.2	28.5
107	26.8	30.7	27.5	30.1	28.1
108	26.6	30.4	27.6	29.7	27.8
109	26.3	30.1	27.3	29.4	27.6
110	26.9	29.8	27.0	28.8	27.2
111	25.6	29.5	26.9	28.5	26.9
112	25.0	29.2	26.5	28.1	26.7
113	26.5	29.0	26.4	27.9	26.5
114	25.8	28.6	26.4	27.7	26.4
115	26.7	28.2	26.1	27.3	26.2
116	25.6	28.0	26.0	27.1	26.1
117	26.8	28.1	26.1	27.1	26.2
118	24.6	27.8	26.7	26.8	26.0
119	25.5	27.5	26.6	26.5	25.8
120	24.7	28.2	25.4	26.0	25.2
121	25.5	28.4	26.7	26.3	25.8
122	24.5	27.7	25.6	26.2	25.1
123	24.9	28.1	25.9	26.5	25.7
124	25.2	28.7	26.3	26.6	25.7
125	25.4	29.0	26.5	26.8	25.6
126	26.0	30.7	26.7	27.2	26.3
127	25.9	31.2	26.6	27.9	26.0
128	26.4	29.9	27.5	26.4	27.2
129	27.2	30.3	28.1	28.5	27.6
130	25.5	30.2	28.2	28.3	27.4
131	24.0	30.1	28.3	28.1	27.2
132	24.6	29.2	27.4	27.7	26.7
133	23.0	28.6	26.3	26.7	24.8
134	21.6	26.1	25.9	24.2	24.0
135	21.7	25.7	25.2	23.8	23.5
136	21.5	25.3	25.1	23.2	23.0
137	20.9	25.0	24.5	22.6	22.7
138	21.1	23.0	22.5	21.8	21.2
139	21.4	22.4	21.2	21.6	20.4

Table B-1(continued) The results of temperature during composting process

Time (Days)	Temperature				
	Room	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**
140	21.5	22.1	21.2	21.5	20.3
141	21.7	22.2	21.2	21.5	20.1
142	20.3	22.0	20.6	21.2	19.9
143	20.9	21.5	20.4	20.9	20.0
144	19.6	21.4	20.3	20.7	19.8
145	18.7	21.1	20.1	20.5	19.8
146	19.8	21.3	20.4	20.2	20.4
147	20.2	20.5	20.2	20.0	20.1
148	20.3	20.3	20.0	19.8	20.0
149	20.0	20.1	20.0	19.7	19.8
150	19.8	20.0	20.1	19.6	19.4
151	20.1	20.3	20.6	19.8	19.5
152	20.3	20.7	20.8	20.0	19.6
153	20.6	21.0	21.2	20.2	19.7
154	20.5	20.8	21.1	20.0	19.5
155	20.3	21.2	21.3	20.1	19.6

Table B-2 The results of pH during composting process

Time	pH			
	Pile 1	**Pile 2**	**Pile 3**	**Pile 4**
0	8.43	8.80	8.58	8.29
7	8.68	9.03	8.87	8.77
14	7.88	8.15	8.07	7.80
21	8.03	7.87	7.87	7.80
28	7.96	8.30	8.13	7.80
35	7.83	8.01	7.83	7.74
42	7.78	8.05	7.94	7.76
49	7.64	7.77	7.62	7.57
56	7.69	7.86	7.77	7.61
63	7.68	7.72	7.69	7.66
70	7.88	7.77	7.71	7.61
77	7.90	7.88	7.76	7.84
84	8.01	7.92	7.87	7.87
91	8.00	7.90	7.84	7.85
98	7.93	7.91	7.79	7.89
105	7.89	7.87	7.86	7.90
112	7.82	7.81	7.93	7.91
119	7.87	7.82	7.98	7.97
126	7.91	7.87	7.95	7.97
133	7.88	7.90	7.99	7.97
140	7.92	7.90	7.95	7.97

Table B-3 The results of moisture contents during composting process

Time	Moisture content (%)			
	Pile 1	Pile 2	Pile 3	Pile 4
0	61.83	61.09	61.56	57.70
7	62.29	63.04	59.04	53.07
14	59.22	58.62	54.61	50.76
21	57.73	57.86	54.50	50.63
28	63.02	60.06	53.61	53.10
35	61.30	61.69	56.75	54.00
42	60.85	57.72	59.90	56.88
49	59.01	58.66	56.57	56.98
56	59.67	59.99	58.53	56.22
63	57.88	58.23	57.31	56.71
70	56.67	57.00	57.81	57.26
77	58.31	58.76	55.67	56.80
84	57.11	58.54	57.43	57.64
91	55.43	58.97	57.88	55.33
98	56.78	56.76	56.70	57.82
105	54.87	56.34	58.41	57.69
112	57.98	58.61	57.94	56.90
119	56.54	55.67	57.01	57.32
126	59.09	58.60	58.34	57.71
133	55.67	56.23	56.41	55.69
140	56.81	56.03	55.35	56.39

Table B-4 The results of total volatile solid during composting process

Time	Total volatile solid (%)			
	Pile 1	Pile 2	Pile 3	Pile 4
0	77.48	70.67	71.12	74.71
7	71.15	69.11	69.23	71.75
14	70.67	64.53	67.66	72.67
21	65.67	65.14	67.92	69.94
28	60.37	63.84	65.29	63.86
35	50.22	60.02	62.24	54
42	45.76	59.83	60.54	53.36
49	44.37	58.56	52.72	52.94
56	44.08	56.96	53.27	48.72
63	43.41	55.26	47.51	45.33
70	36.98	49.22	48.01	44.09
77	37.71	49.12	47.21	43.07
84	33.86	45.59	39.75	36.71
91	33.55	40.09	38.06	33.67
98	33.71	39.38	35.11	30.16
105	32.8	35.51	36.14	31.36
112	31.19	34.92	34.95	30.99
119	31.27	33.95	33.12	29.59
126	30.94	32.11	33.54	28.54
133	31.07	32.45	32.9	28.96
140	31.32	32.05	33.32	28.06

Table B-5 The results of total organic carbon during composting process

Time	Total organic carbon (%)			
	Pile 1	**Pile 2**	**Pile 3**	**Pile 4**
0	44.4	37.5	38.8	42.8
7	42.4	36.8	35.5	39.9
14	38.7	36.8	36.3	38.7
21	35.2	37.0	36.7	35.2
28	31.5	35.8	36.7	34.1
35	30.9	34.2	34.4	32.5
42	27.7	33.5	33.7	29.8
49	28.1	33.4	32.3	29.5
56	26.1	31.3	30.3	27.7
63	24.6	29.7	29.9	26.3
70	22.3	29.7	28.4	24.4
77	21.3	27.3	26.8	22.1
84	19.1	24.7	24.2	20.5
91	19.7	22.7	20.9	19.0
98	19.0	20.5	19.8	16.9
105	18.9	20.0	19.6	18.8
112	18.3	20.1	19.4	18.8
119	18.7	19.2	18.6	17.7
126	19.3	18.9	19.2	16.6
133	18.3	18.7	18.8	17.1
140	17.6	18.2	18.2	16.3

Table B-6 The results of total nitrogen during composting process

Time	Total nitrogen (%)			
	Pile 1	**Pile 2**	**Pile 3**	**Pile 4**
0	1.71	1.50	1.51	1.68
7	1.66	1.46	1.41	1.60
14	1.57	1.51	1.50	1.52
21	1.63	1.49	1.58	1.46
28	1.53	1.45	1.56	1.53
35	1.48	1.40	1.49	1.50
42	1.43	1.40	1.44	1.49
49	1.42	1.40	1.49	1.52
56	1.55	1.47	1.49	1.47
63	1.52	1.49	1.51	1.47
70	1.49	1.52	1.48	1.46
77	1.42	1.49	1.51	1.49
84	1.49	1.50	1.49	1.46
91	1.48	1.46	1.52	1.51
98	1.53	1.47	1.51	1.59
105	1.48	1.46	1.41	1.46
112	1.45	1.39	1.44	1.47
119	1.47	1.47	1.49	1.40
126	1.52	1.46	1.47	1.40
133	1.40	1.43	1.45	1.50
140	1.36	1.39	1.41	1.48

Table B-7 The results of C/N ratio during composting process

Time	C/N			
	Pile 1	Pile 2	Pile 3	Pile 4
0	25.99	25.01	25.72	25.50
7	25.60	25.23	25.23	25.00
14	24.59	24.46	24.28	25.48
21	21.63	24.81	23.19	24.13
28	20.58	24.78	23.53	22.28
35	20.90	24.54	23.01	21.65
42	19.37	23.96	23.41	19.96
49	19.80	23.81	21.66	19.44
56	16.83	21.36	20.39	18.83
63	16.15	19.95	19.78	17.85
70	14.98	19.59	19.18	16.72
77	14.97	18.37	17.71	14.80
84	12.77	16.49	16.25	14.09
91	13.32	15.49	13.76	12.61
98	12.40	13.98	13.13	10.66
105	12.77	13.74	13.91	12.90
112	12.63	14.49	13.50	12.81
119	12.78	13.06	12.55	12.67
126	12.71	12.88	13.02	11.87
133	13.08	13.11	12.96	11.47
140	12.93	13.10	12.88	11.05

Table B-8 The results of Germination index during composting process

Time	GI (%)			
	Pile 1	Pile 2	Pile 3	Pile 4
44	163.95	123.94	119.41	114.81
58	166.58	144.70	122.21	120.42
68	171.61	163.48	133.04	128.77
78	172.88	150.64	132.21	123.85
88	177.49	147.90	134.13	122.00
95	182.85	150.82	144.86	135.29
102	193.57	160.57	147.47	139.28
109	199.84	156.52	145.54	125.93
116	201.68	153.19	129.07	111.68
126	205.98	155.23	130.61	111.71
136	210.46	157.80	131.73	113.31
147	217.59	156.76	132.47	114.54

Table B-9 The results of Total concentration of Cu, Cr and As of compost pile 1 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
0	0.74	0.66	0.70	35.10	0.38	0.38	0.38	18.88	0.31	0.31	0.31	15.32
7	0.54	0.58	0.56	28.00	0.34	0.34	0.34	16.89	0.32	0.31	0.31	15.73
14	0.61	0.60	0.60	30.10	0.29	0.30	0.29	14.63	0.31	0.31	0.31	15.45
21	0.59	0.56	0.58	28.85	0.38	0.38	0.38	18.86	0.36	0.36	0.36	17.95
28	0.59	0.58	0.58	29.15	0.26	0.26	0.26	12.86	0.38	0.38	0.38	18.85
35	0.58	0.58	0.58	29.03	0.20	0.20	0.20	10.09	0.40	0.36	0.38	18.91
42	0.58	0.59	0.58	29.08	0.22	0.21	0.21	10.58	0.42	0.41	0.42	20.76
49	0.57	0.57	0.57	28.50	0.24	0.26	0.25	12.33	0.43	0.43	0.43	21.48
56	0.53	0.60	0.56	28.10	0.25	0.22	0.23	11.69	0.46	0.44	0.45	22.38
63	0.54	0.52	0.53	26.53	0.35	0.36	0.35	17.65	0.47	0.47	0.47	23.43
70	0.61	0.62	0.61	30.53	0.45	0.45	0.45	22.28	0.48	0.48	0.48	23.83
77	0.68	0.67	0.68	33.80	0.73	0.73	0.73	36.59	0.47	0.47	0.47	23.42
84	0.71	0.70	0.71	35.30	0.76	0.80	0.78	38.96	0.47	0.48	0.48	23.81
91	0.64	0.65	0.64	32.05	0.84	0.79	0.82	40.84	0.44	0.45	0.45	22.34
98	0.62	0.62	0.62	30.95	0.90	0.89	0.89	44.64	0.44	0.45	0.44	22.12
105	0.60	0.59	0.60	29.78	0.88	0.91	0.89	44.69	0.42	0.41	0.41	20.66
112	0.69	0.68	0.69	34.25	0.89	0.90	0.90	44.75	0.44	0.42	0.43	21.39
119	0.66	0.65	0.65	32.60	0.76	0.89	0.82	41.15	0.44	0.44	0.44	22.00
126	0.56	0.56	0.56	27.95	0.83	0.84	0.84	41.90	0.43	0.44	0.44	21.78
133	0.57	0.57	0.57	28.50	0.89	0.90	0.89	44.65	0.49	0.47	0.48	23.82
140	0.60	0.60	0.60	29.98	0.89	0.90	0.89	44.73	0.47	0.45	0.46	22.98

Note. Using 2 g of samples and dilute the digested sample into 100 ml volumetric flask

Table B-10 The results of Total concentration of Cu, Cr and As of compost pile 2 during composting process

Time	**Cu**				**Cr**				**As**			
	Conc. Read (mg/l)		**Average (mg/l)**	**Concentration (mg/kg)**	**Conc. Read (mg/l)**		**Average (mg/l)**	**Concentration (mg/kg)**	**Conc. Read (mg/l)**		**Average (mg/l)**	**Concentration (mg/kg)**
	1	**2**			**1**	**2**			**1**	**2**		
0	3.83	3.79	3.81	190.38	1.54	1.47	1.51	376.50	4.28	4.55	4.41	220.68
7	3.80	3.80	3.80	189.94	1.47	1.47	1.47	364.25	4.05	4.04	4.04	202.20
14	4.06	4.04	4.05	202.38	1.60	1.53	1.57	391.75	4.13	4.02	4.08	203.88
21	3.81	3.86	3.84	191.75	1.40	1.40	1.40	352.63	4.04	3.94	3.99	199.33
28	4.08	4.11	4.10	204.75	1.51	1.57	1.54	384.13	4.16	4.24	4.20	210.18
35	4.50	4.47	4.48	224.00	1.80	1.85	1.83	451.25	4.29	4.20	4.25	212.43
42	5.46	5.56	5.51	275.50	1.81	1.89	1.85	462.13	4.43	4.58	4.50	225.10
49	5.16	6.00	5.58	278.88	1.70	1.66	1.68	427.88	4.64	4.73	4.69	234.38
56	6.30	6.00	6.15	307.38	2.23	2.34	2.28	570.13	4.80	4.72	4.76	237.85
63	6.05	5.96	6.00	300.00	2.25	2.22	2.24	558.75	4.84	4.86	4.85	242.45
70	5.80	6.56	6.18	308.88	2.02	2.17	2.09	526.13	5.24	5.44	5.34	266.78
77	5.92	5.89	5.91	295.28	2.06	2.09	2.07	517.38	5.53	5.67	5.60	279.98
84	6.51	6.63	6.57	328.50	2.30	2.29	2.30	573.25	6.04	5.95	6.00	299.75
91	7.56	8.04	7.80	389.75	2.31	2.32	2.31	573.50	6.12	6.20	6.16	308.10
98	8.02	7.96	7.99	399.38	2.25	2.27	2.26	563.75	6.48	6.53	6.51	325.33
105	7.97	7.22	7.59	379.63	2.34	2.34	2.34	584.75	6.79	6.83	6.81	340.55
112	7.36	7.40	7.38	369.00	2.41	2.26	2.33	582.00	7.64	7.55	7.60	379.93
119	7.47	7.42	7.44	372.13	2.78	2.78	2.78	694.00	7.45	7.65	7.55	377.38
126	7.80	7.97	7.89	394.25	2.92	2.83	2.88	718.75	7.65	7.99	7.82	391.19
133	7.89	7.92	7.90	395.00	2.65	2.73	2.69	677.38	7.68	7.88	7.78	388.83
140	7.88	7.91	7.90	394.75	2.81	2.81	2.81	702.25	7.99	7.65	7.82	391.15

Note. Using 2 g of samples and dilute the digested sample into 100 ml volumetric flask

Table B-11 The results of Total concentration of Cu, Cr and As of compost pile 3 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
0	6.19	6.00	6.09	304.50	12.09	12.41	12.25	612.38	11.15	11.10	11.13	556.35
7	5.79	5.73	5.76	287.88	12.22	12.16	12.19	609.50	10.86	10.79	10.83	541.30
14	6.68	6.87	6.78	338.75	13.18	12.72	12.95	647.25	11.23	11.06	11.15	557.30
21	6.54	6.52	6.53	326.50	13.06	13.45	13.25	662.63	11.00	11.09	11.05	552.25
28	7.50	7.47	7.48	374.13	13.50	13.41	13.45	672.63	11.33	11.19	11.26	562.85
35	7.54	7.59	7.57	378.25	13.99	14.35	14.17	708.38	11.39	11.19	11.29	564.35
42	9.49	9.27	9.38	468.88	13.06	13.08	13.07	653.50	11.65	11.55	11.60	580.20
49	9.78	9.13	9.46	472.75	13.77	13.86	13.81	690.63	11.23	11.43	11.33	566.35
56	10.52	10.78	10.65	532.25	15.49	16.53	16.01	800.38	11.38	11.43	11.41	570.35
63	13.59	12.54	13.06	653.00	17.84	17.76	17.80	890.00	11.03	11.18	11.11	555.30
70	15.98	15.91	15.94	797.13	18.41	18.38	18.40	919.75	12.20	12.19	12.19	609.70
77	16.73	16.84	16.78	839.13	22.78	22.94	22.86	1142.88	13.54	13.80	13.67	683.40
84	19.23	18.76	19.00	949.75	29.78	29.93	29.85	1492.50	13.86	14.37	14.12	705.85
91	20.03	20.07	20.05	1002.50	35.31	35.99	35.65	1782.50	14.75	14.51	14.63	731.65
98	19.96	19.32	19.64	981.75	36.25	36.39	36.32	1816.00	14.57	14.45	14.51	725.50
105	19.16	19.89	19.52	976.13	37.64	37.21	37.43	1871.25	14.68	14.35	14.52	725.75
112	18.00	18.28	18.14	906.75	37.72	38.02	37.87	1893.50	15.25	15.72	15.49	774.25
119	18.81	18.83	18.82	940.88	39.41	38.95	39.18	1959.00	14.76	14.96	14.86	743.00
126	18.49	18.53	18.51	925.25	39.02	39.57	39.30	1964.75	15.65	15.25	15.45	772.50
133	19.14	19.19	19.16	958.13	39.98	39.50	39.74	1987.00	15.75	15.45	15.60	780.00
140	19.23	19.33	19.28	963.88	39.91	39.99	39.95	1997.50	15.05	15.19	15.12	756.00

Note. Using 2 g of samples and dilute the digested sample into 100 ml volumetric flask

Table B-12 The results of Total concentration of Cu, Cr and As of compost pile 4 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
0	6.19	6.00	6.09	304.50	12.09	12.41	12.25	612.38	13.51	13.48	13.50	674.75
7	5.79	5.73	5.76	287.88	12.22	12.16	12.19	609.50	13.05	12.97	13.01	650.38
14	6.68	6.87	6.78	338.75	13.18	12.72	12.95	647.25	13.44	13.52	13.48	673.75
21	6.54	6.52	6.53	326.50	13.06	13.45	13.25	662.63	13.34	13.38	13.36	667.88
28	7.50	7.47	7.48	374.13	13.50	13.41	13.45	672.63	14.16	13.88	14.02	700.88
35	7.54	7.59	7.57	378.25	13.99	14.35	14.17	708.38	17.00	16.21	16.60	830.13
42	9.49	9.27	9.38	468.88	13.06	13.08	13.07	653.50	18.84	18.51	18.67	933.63
49	9.78	9.13	9.46	472.75	13.77	13.86	13.81	690.63	19.26	18.83	19.04	952.13
56	10.52	10.78	10.65	532.25	15.49	16.53	16.01	800.38	21.85	22.32	22.08	1104.00
63	13.59	12.54	13.06	653.00	17.84	17.76	17.80	890.00	26.59	26.81	26.70	1335.00
70	15.98	15.91	15.94	797.13	18.41	18.38	18.40	919.75	30.58	31.64	31.11	1555.50
77	16.73	16.84	16.78	839.13	22.78	22.94	22.86	1142.88	34.75	34.21	34.48	1724.00
84	19.23	18.76	19.00	949.75	29.78	29.93	29.85	1492.50	39.35	38.95	39.15	1957.50
91	20.03	20.07	20.05	1002.50	35.31	35.99	35.65	1782.50	40.02	40.31	40.17	2008.25
98	19.96	19.32	19.64	981.75	36.25	36.39	36.32	1816.00	39.95	39.32	39.64	1981.75
105	19.16	19.89	19.52	976.13	37.64	37.21	37.43	1871.25	37.72	37.57	37.65	1882.25
112	18.00	18.28	18.14	906.75	37.72	38.02	37.87	1893.50	35.12	36.02	35.57	1778.50
119	18.81	18.83	18.82	940.88	39.41	38.95	39.18	1959.00	37.06	37.13	37.10	1854.75
126	18.49	18.53	18.51	925.25	39.02	39.57	39.30	1964.75	39.13	39.43	39.28	1964.00
133	19.14	19.19	19.16	958.13	39.98	39.50	39.74	1987.00	35.24	35.96	35.60	1780.00
140	19.23	19.33	19.28	963.88	39.91	39.99	39.95	1997.50	34.61	34.43	34.52	1726.00

Note. Using 2 g of samples and dilute the digested sample into 100 ml volumetric flask

Table B-13 The results of the concentration of Cu, Cr and As in fraction 1 (water soluble) of compost pile1 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (μg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	BDL*	BDL	BDL	BDL	BDL	BDL	BDL	BDL	54.36	49.83	52.10	2.60
14	0.07	0.05	0.06	3.08	BDL	BDL	BDL	BDL	30.90	42.21	36.56	1.83
21	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	37.83	32.45	35.14	1.76
28	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	45.09	64.10	54.60	2.73
35	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	20.56	25.60	23.08	1.15
42	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	22.30	20.04	21.17	1.06
49	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	22.95	23.01	22.98	1.15
56	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	30.02	32.15	31.09	1.55
63	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	70.32	73.32	71.82	3.59
70	BDL	0.05	0.04	2.15	0.36	0.50	0.43	2.15	160.43	168.34	164.39	8.22
77	BDL	BDL	BDL	1.68	0.48	BDL	0.24	1.20	140.35	66.29	103.32	5.17
84	BDL	BDL	BDL	0.90	BDL	BDL	BDL	BDL	202.14	127.56	164.85	8.24
91	BDL	BDL	BDL	0.00	BDL	BDL	BDL	BDL	165.48	176.57	171.03	8.55
98	BDL	BDL	BDL	0.00	BDL	BDL	BDL	BDL	106.65	39.77	73.21	3.66
105	BDL	BDL	BDL	0.00	BDL	BDL	BDL	BDL	69.53	47.54	58.54	2.93
112	0.06	0.06	0.06	3.10	BDL	0.06	0.04	0.18	103.91	88.43	96.17	4.81
119	BDL	BDL	BDL	BDL	0.45	BDL	0.23	1.13	116.94	91.47	104.21	5.21
126	BDL	BDL	BDL	BDL	0.08	0.21	0.15	0.73	142.30	153.76	148.03	7.40
133	BDL	BDL	BDL	BDL	BDL	0.10	0.07	0.33	271.56	190.32	230.94	11.55
140	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	293.25	201.02	247.14	12.36

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)

Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-14 The results of the concentration of Cu, Cr and As in fraction 1 (water soluble) of compost pile2 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (µg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	0.14	0.16	0.15	7.65	BDL*	BDL	BDL	BDL	194.53	184.00	189.27	9.46
14	0.20	0.14	0.17	8.53	BDL	BDL	BDL	BDL	166.32	190.56	178.44	8.92
21	0.14	0.15	0.14	7.08	BDL	BDL	BDL	BDL	212.04	299.89	255.97	12.80
28	BDL	0.19	0.09	4.70	BDL	BDL	BDL	BDL	382.02	308.38	345.20	17.26
35	0.16	0.13	0.14	7.23	BDL	BDL	BDL	BDL	498.39	465.03	481.71	24.09
42	0.20	0.15	0.17	8.65	BDL	BDL	BDL	BDL	510.49	592.34	551.42	27.57
49	0.14	0.18	0.16	7.95	BDL	BDL	BDL	BDL	671.11	674.40	672.76	33.64
56	0.18	0.17	0.18	8.75	BDL	BDL	BDL	BDL	700.32	703.39	701.86	35.09
63	0.29	0.20	0.25	12.3	BDL	BDL	BDL	BDL	700.34	710.45	705.40	35.27
70	0.24	0.23	0.24	11.9	0.24	0.23	0.24	11.9	731.26	740.02	735.64	36.78
77	0.22	0.22	0.22	10.9	BDL	BDL	BDL	BDL	804.37	812.74	808.56	40.43
84	0.23	0.23	0.23	11.3	BDL	BDL	BDL	BDL	1006.6	1019.3	1012.9	50.65
91	0.22	0.22	0.22	11.0	BDL	BDL	BDL	BDL	1380.0	1405.3	1392.6	69.63
98	0.20	0.21	0.21	10.3	BDL	BDL	BDL	BDL	1658.8	1673.4	1666.1	83.30
105	0.22	0.19	0.21	10.2	BDL	BDL	BDL	BDL	1890.9	1904.5	1897.7	94.88
112	0.28	0.27	0.28	13.8	BDL	BDL	BDL	BDL	1943.3	1947.0	1945.2	97.26
119	0.28	0.29	0.28	14.1	0.09	0.08	0.09	4.43	1760.4	1763.8	1762.1	88.11
126	0.23	0.27	0.25	12.5	BDL	BDL	BDL	BDL	1894.6	1810.0	1852.4	92.62
133	0.25	0.23	0.24	12.0	BDL	BDL	BDL	BDL	1903.3	2002.1	1952.7	97.64
140	0.28	0.22	0.25	12.4	BDL	BDL	BDL	BDL	2004.9	2009.8	2007.3	100.4

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)

Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-15 The results of the concentration of Cu, Cr and As in fraction 1 (water soluble) of compost pile 3 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (µg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	0.20	0.25	0.23	11.40	BDL*	BDL	BDL	BDL	554.63	585.84	570.24	28.51
14	0.23	0.26	0.25	12.28	BDL	BDL	BDL	BDL	554.35	518.09	536.22	26.81
21	0.21	0.28	0.25	12.28	BDL	BDL	BDL	BDL	560.98	570.26	565.62	28.28
28	0.28	0.24	0.26	13.18	BDL	BDL	BDL	BDL	664.74	659.82	662.28	33.11
35	0.26	0.33	0.29	14.73	BDL	BDL	BDL	BDL	762.18	774.48	768.33	38.42
42	0.33	0.41	0.37	18.38	BDL	BDL	BDL	BDL	850.78	905.54	878.16	43.91
49	0.31	0.30	0.30	15.20	BDL	BDL	BDL	BDL	733.02	720.73	726.88	36.34
56	0.42	0.34	0.38	18.78	BDL	BDL	BDL	BDL	739.96	734.28	737.12	36.86
63	0.44	0.37	0.41	20.33	BDL	BDL	BDL	BDL	754.35	770.98	762.67	38.13
70	0.37	0.37	0.37	18.50	0.37	0.37	0.37	18.5	890.35	902.43	896.39	44.82
77	0.32	0.34	0.33	16.63	0.11	0.10	0.10	5.18	1002.3	980.98	991.66	49.58
84	0.35	0.37	0.36	18.08	0.06	BDL	0.04	2.00	1567.7	1559.0	1563.3	78.17
91	0.36	0.36	0.36	17.95	BDL	BDL	BDL	BDL	1756.6	1780.2	1768.4	88.42
98	0.35	0.35	0.35	17.45	BDL	BDL	BDL	BDL	2047.7	2090.5	2069.1	103.4
105	0.36	0.36	0.36	18.13	BDL	BDL	BDL	BDL	2065.6	2070.9	2068.3	103.4
112	0.43	0.45	0.44	22.10	0.07	0.07	0.07	3.40	2073.0	2047.8	2060.4	103.0
119	0.49	0.50	0.50	24.75	0.11	0.16	0.13	6.73	2000.1	2040.2	2020.1	101.0
126	0.33	0.35	0.34	16.93	0.09	0.10	0.09	4.73	2153.4	2147.9	2150.6	107.5
133	0.30	0.36	0.33	16.28	0.10	BDL	0.07	3.58	2070.1	2117.8	2093.9	104.7
140	0.32	0.37	0.35	17.28	0.05	BDL	0.05	2.33	2109.8	2146.7	2128.3	106.4

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)
Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-16 The results of the concentration of Cu, Cr and As in fraction 1 (water soluble) of compost pile 4 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (µg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	0.47	0.34	0.40	20.03	0.10	0.08	0.09	4.43	690.45	676.70	683.58	34.18
14	0.46	0.37	0.41	20.68	BDL*	0.12	0.08	3.95	695.64	648.76	672.20	33.61
21	0.37	0.42	0.39	19.58	0.12	0.10	0.11	5.48	674.27	672.10	673.19	33.66
28	0.37	0.43	0.40	20.05	0.07	0.06	0.07	3.25	781.07	778.47	779.77	38.99
35	0.37	0.49	0.43	21.48	0.06	0.07	0.06	3.13	870.70	894.60	882.65	44.13
42	0.46	0.52	0.49	24.58	0.15	BDL	0.08	3.80	980.03	994.56	987.30	49.36
49	0.47	0.49	0.48	23.93	0.06	BDL	0.03	1.43	743.84	740.58	742.21	37.11
56	0.55	0.49	0.52	26.03	BDL	BDL	BDL	BDL	747.35	746.76	747.06	37.35
63	0.53	0.52	0.52	26.15	BDL	BDL	BDL	BDL	806.54	820.13	813.34	40.67
70	0.49	0.49	0.49	24.35	0.49	0.49	0.49	24.3	1003.6	1045.5	1024.5	51.23
77	0.46	0.45	0.45	22.73	0.12	0.18	0.15	7.48	1670.9	1734.5	1702.7	85.13
84	0.55	0.47	0.51	25.48	0.07	0.08	0.08	3.75	1989.9	2004.4	1997.1	99.86
91	0.47	0.48	0.47	23.70	BDL	BDL	BDL	BDL	2432.5	2506.8	2469.7	123.5
98	0.44	0.45	0.44	22.05	BDL	BDL	BDL	BDL	2486.2	2476.9	2481.6	124.1
105	0.43	0.46	0.44	22.20	BDL	BDL	BDL	BDL	2300.9	2390.9	2345.9	117.3
112	0.55	0.57	0.56	27.93	0.26	BDL	0.14	6.78	2315.0	2331.0	2323.0	116.1
119	0.74	0.74	0.74	36.98	0.15	0.24	0.19	9.70	2302.3	2386.5	2344.4	117.2
126	0.55	0.57	0.56	28.00	0.10	0.23	0.16	8.23	2369.3	2372.3	2370.8	118.5
133	0.54	0.56	0.55	27.43	0.09	0.08	0.08	4.05	2397.7	2301.2	2349.4	117.5
140	0.59	0.59	0.59	29.58	0.07	BDL	0.05	2.68	2358.9	2341.8	2350.3	117.5

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)

Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-17 The results of the concentration of Cu, Cr and As in fraction 2 (exchangeable) of compost pile 1 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (µg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	BDL*	BDL	BDL	BDL	BDL	BDL	BDL	BDL	50.93	49.90	50.42	2.52
14	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	46.54	51.90	49.22	2.46
21	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	49.06	36.72	42.89	2.14
28	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	40.97	24.90	32.94	1.65
35	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	46.08	47.63	46.86	2.34
42	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	47.92	52.30	50.11	2.51
49	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	35.43	54.27	44.85	2.24
56	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	32.45	39.07	35.76	1.79
63	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	139.4	128.9	134.15	6.71
70	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	96.54	56.54	76.54	3.83
77	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	90.44	86.65	88.55	4.43
84	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	95.43	80.90	88.16	4.41
91	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	109.6	113.2	111.5	5.57
98	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	165.4	187.7	176.5	8.83
105	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	126.5	106.5	116.5	5.83
112	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	102.1	129.6	115.9	5.79
119	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	123.2	115.3	119.3	5.96
126	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	106.5	154.4	130.5	6.52
133	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	95.4	96.54	95.9	4.80
140	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	105.5	96.54	101.0	5.05

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)
Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-18 The results of the concentration of Cu, Cr and As in fraction 2 (exchangeable) of compost pile 2 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (µg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	BDL*	BDL	0.00	0.00	0.10	0.09	0.09	4.68	294.27	250.07	272.17	13.61
14	BDL	BDL	0.00	0.00	0.11	BDL	0.05	2.63	236.43	230.60	233.52	11.68
21	BDL	BDL	0.00	0.00	BDL	BDL	0.00	0.00	392.45	338.61	365.53	18.28
28	BDL	BDL	0.00	0.00	BDL	BDL	0.00	0.00	473.75	470.14	471.95	23.60
35	BDL	BDL	0.00	0.00	BDL	BDL	0.00	0.00	435.14	388.02	411.58	20.58
42	BDL	BDL	0.00	0.00	BDL	BDL	0.00	0.00	464.56	436.43	450.50	22.52
49	BDL	BDL	0.00	0.00	BDL	BDL	0.00	0.18	511.63	432.20	471.92	23.60
56	BDL	BDL	0.00	0.00	BDL	BDL	0.01	0.70	493.41	443.60	468.51	23.43
63	BDL	BDL	0.00	0.00	BDL	BDL	0.00	0.00	463.65	459.80	461.73	23.09
70	BDL	BDL	0.00	0.13	BDL	BDL	0.00	0.13	879.87	880.98	880.42	44.02
77	BDL	BDL	0.01	0.48	BDL	BDL	0.04	2.15	1006.5	1015.4	1010.9	50.55
84	BDL	BDL	0.01	0.55	BDL	BDL	0.00	0.05	1045.4	1093.2	1069.3	53.47
91	BDL	BDL	0.00	0.00	BDL	BDL	0.00	0.00	950.3	935.4	942.88	47.14
98	BDL	BDL	0.00	0.00	BDL	BDL	0.00	0.00	934.3	954.3	944.33	47.22
105	BDL	BDL	0.00	0.00	BDL	BDL	0.00	0.00	1205.4	1216.5	1210.9	60.55
112	BDL	BDL	0.03	1.53	BDL	BDL	0.04	2.13	1235.4	1229.9	1232.6	61.63
119	BDL	BDL	0.03	1.58	BDL	BDL	0.00	0.00	1256.5	1265.4	1260.9	63.05
126	BDL	BDL	0.02	1.18	BDL	BDL	0.01	0.28	1236.8	1234.3	1235.5	61.78
133	BDL	BDL	0.01	0.26	BDL	BDL	0.00	0.00	1215.4	1229.9	1222.6	61.13
140	BDL	BDL	0.00	0.23	BDL	BDL	0.00	0.00	1248.8	1246.5	1247.6	62.38

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)
Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-19 The results of the concentration of Cu, Cr and As in fraction 2 (exchangeable) of compost pile 3 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (µg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	BDL*	BDL	BDL	BDL	0.20	0.08	0.14	6.78	576.48	651.58	614.03	30.70
14	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	663.44	662.02	662.73	33.14
21	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	499.04	507.80	503.42	25.17
28	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	559.65	539.07	549.36	27.47
35	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	683.20	594.67	638.94	31.95
42	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	691.50	689.23	690.37	34.52
49	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	626.64	667.65	647.15	32.36
56	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	610.94	647.86	629.40	31.47
63	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	647.86	610.96	629.41	31.47
70	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	1204.3	1203.0	1203.7	60.18
77	0.06	BDL	0.03	1.53	0.11	0.09	0.10	4.88	1542.8	1555.0	1548.9	77.44
84	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	1369.5	1350.5	1360.0	68.00
91	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	1305.5	1300.0	1302.7	65.14
98	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	1315.4	1319.4	1317.4	65.87
105	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	2005.4	2036.5	2020.9	101.0
112	0.05	BDL	0.04	2.15	0.07	BDL	0.06	3.05	2254.3	2238.6	2246.5	112.3
119	0.08	0.07	0.07	3.73	BDL	BDL	BDL	BDL	2237.7	2237.6	2237.7	111.9
126	0.07	0.07	0.07	3.33	BDL	BDL	BDL	BDL	2224.5	2229.1	2226.8	111.3
133	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	2269.5	2260.4	2264.9	113.2
140	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	2258.8	2260.4	2259.6	112.9

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)
Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-20 The results of the concentration of Cu, Cr and As in fraction 2 (exchangeable) of compost pile 4 during composting process

	Cu				**Cr**				**As**			
	Conc. Read (mg/l)		**Average (mg/l)**	**Concentration (mg/kg)**	**Conc. Read (mg/l)**		**Average (mg/l)**	**Concentration (mg/kg)**	**Conc. Read (mg/l)**		**Average (µg/l)**	**Concentration (mg/kg)**
	1	**2**			**1**	**2**			**1**	**2**		
7	BDL*	BDL	BDL	BDL	0.20	0.13	0.17	8.27	661.58	662.67	662.13	33.11
14	BDL	BDL	BDL	BDL	BDL	0.12	0.06	3.00	686.89	684.54	685.72	34.29
21	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	768.39	734.39	751.39	37.57
28	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	759.65	739.07	749.36	37.47
35	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	855.59	850.08	852.84	42.64
42	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	710.85	729.20	720.03	36.00
49	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	708.79	680.34	694.57	34.73
56	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	704.53	676.50	690.52	34.53
63	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	698.07	687.09	692.58	34.63
70	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	1565.5	1560.4	1562.9	78.15
77	0.08	0.09	0.08	4.18	0.15	0.13	0.14	6.88	2006.5	2005.9	2006.1	100.3
84	BDL	BDL	BDL	BDL	0.12	0.08	0.10	4.98	1750.5	1756.6	1753.6	87.68
91	BDL	BDL	BDL	BDL	0.10	BDL	0.07	3.30	1610.9	1610.3	1610.7	80.53
98	BDL	BDL	BDL	BDL	0.18	BDL	0.11	5.53	1604.4	1604.3	1604.4	80.22
105	BDL	BDL	BDL	BDL	0.11	0.09	0.10	5.08	2590.4	2609.9	2600.2	130.0
112	BDL	BDL	BDL	BDL	0.30	0.07	0.18	9.20	2789.8	2786.5	2788.1	139.4
119	0.11	0.09	0.10	5.13	0.10	BDL	0.06	2.95	2760.5	2760.9	2760.7	138.0
126	BDL	BDL	BDL	BDL	0.11	BDL	0.07	3.58	2773.2	2773.8	2773.5	138.7
133	BDL	BDL	BDL	BDL	BDL	0.05	0.05	2.50	2760.4	2760.0	2760.2	138.0
140	BDL	BDL	BDL	BDL	BDL	0.08	0.04	2.03	2789.0	2789.8	2789.4	139.5

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)

Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-21 The results of the concentration of Cu, Cr and As in fraction 3 (carbonate bound) of compost pile 1 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	BDL*	BDL	BDL	BDL	BDL	BDL	BDL	BDL	ND**	ND	ND	ND
14	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.02	0.01	0.02	0.79
21	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01	0.01	0.01	0.61
28	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01	0.01	0.01	0.74
35	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.02	0.02	0.02	0.81
42	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01	0.00	0.01	0.33
49	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01	0.01	0.01	0.55
56	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.02	0.02	0.02	0.92
63	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.02	0.03	0.03	1.26
70	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01	0.01	0.01	0.60
77	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.03	0.03	0.03	1.49
84	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01	0.02	0.02	0.78
91	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.02	0.02	0.02	0.94
98	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.02	0.01	0.02	0.77
105	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01	0.01	0.01	0.67
112	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01	0.01	0.01	0.30
119	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.00	0.01	0.01	0.27
126	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.02	0.02	0.02	0.77
133	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.02	0.03	0.02	1.18
140	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01	0.01	0.01	0.69

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)
**Not Detectable
Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-22 The results of the concentration of Cu, Cr and As in fraction 3 (carbonate bound) of compost pile 2 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	BDL*	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.61	0.65	0.63	31.59
14	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.68	0.68	0.68	34.12
21	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.69	0.61	0.65	32.50
28	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.78	0.74	0.76	38.01
35	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.75	0.76	0.76	37.84
42	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.74	0.77	0.76	37.81
49	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.77	0.78	0.78	38.76
56	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.77	0.76	0.77	38.26
63	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.79	0.79	0.79	39.62
70	BDL	BDL	BDL	BDL	0.06	BDL	0.05	2.28	0.81	0.90	0.85	42.52
77	BDL	BDL	BDL	BDL	BDL	BDL	0.04	2.23	0.90	0.90	0.90	45.22
84	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.76	0.76	0.76	37.93
91	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.79	0.78	0.78	39.25
98	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.75	0.76	0.76	37.77
105	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.72	0.74	0.73	36.30
112	BDL	BDL	BDL	BDL	0.14	0.12	0.13	6.55	0.66	0.68	0.67	33.46
119	BDL	BDL	BDL	BDL	0.11	0.12	0.12	5.78	0.70	0.68	0.69	34.35
126	BDL	BDL	BDL	BDL	0.09	0.10	0.09	4.73	0.77	0.68	0.72	36.15
133	BDL	BDL	BDL	BDL	0.08	0.08	0.08	3.90	0.67	0.71	0.69	34.40
140	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.75	0.71	0.73	36.53

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)
Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-23 The results of the concentration of Cu, Cr and As in fraction 3 (carbonate bound) of compost pile 3 during composting process

Time	**Cu**				**Cr**				**As**			
	Conc. Read (mg/l)		**Average (mg/l)**	**Concentration (mg/kg)**	**Conc. Read (mg/l)**		**Average (mg/l)**	**Concentration (mg/kg)**	**Conc. Read (mg/l)**		**Average (mg/l)**	**Concentration (mg/kg)**
	1	**2**			**1**	**2**			**1**	**2**		
7	0.08	0.06	0.07	3.35	BDL*	BDL	BDL	BDL	0.69	0.69	0.69	34.41
14	0.05	BDL	0.04	2.00	BDL	BDL	BDL	BDL	0.69	0.69	0.69	34.56
21	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.79	0.78	0.78	39.25
28	0.05	BDL	0.05	2.40	BDL	BDL	BDL	BDL	0.85	0.87	0.86	42.89
35	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.93	0.92	0.92	46.14
42	BDL	BDL	0.02	0.95	BDL	BDL	BDL	BDL	0.90	0.91	0.91	45.37
49	0.05	BDL	0.03	1.43	BDL	BDL	BDL	BDL	0.90	0.89	0.89	44.56
56	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.90	0.90	0.90	45.00
63	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.88	0.84	0.86	42.94
70	0.10	0.08	0.09	4.63	0.10	0.08	0.09	4.63	0.89	0.89	0.89	44.46
77	0.07	0.08	0.07	3.65	0.12	0.13	0.13	6.33	0.98	0.95	0.97	48.33
84	0.08	0.08	0.08	4.03	0.11	0.09	0.10	5.08	0.86	0.88	0.87	43.52
91	0.07	0.07	0.07	3.48	0.13	0.14	0.14	6.85	0.88	0.87	0.87	43.61
98	0.06	0.07	0.06	3.20	0.12	0.12	0.12	5.88	0.86	0.86	0.86	43.10
105	0.05	0.06	0.05	2.73	0.22	0.23	0.22	11.18	0.83	0.83	0.83	41.42
112	0.06	BDL	0.05	2.53	0.18	0.16	0.17	8.30	0.80	0.82	0.81	40.61
119	BDL	BDL	BDL	BDL	0.12	0.12	0.12	6.05	0.80	0.80	0.80	39.96
126	BDL	BDL	BDL	BDL	0.12	0.12	0.12	5.88	0.85	0.85	0.85	42.52
133	BDL	BDL	BDL	BDL	0.12	0.12	0.12	6.03	0.89	0.91	0.90	44.95
140	BDL	BDL	BDL	BDL	0.10	0.08	0.09	4.43	0.90	0.90	0.90	45.08

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)
Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-24 The results of the concentration of Cu, Cr and As in fraction 3 (carbonate bound) of compost pile 4 during composting process

Time	**Cu**				**Cr**				**As**			
	Conc. Read (mg/l)		**Average (mg/l)**	**Concentration (mg/kg)**	**Conc. Read (mg/l)**		**Average (mg/l)**	**Concentration (mg/kg)**	**Conc. Read (mg/l)**		**Average (mg/l)**	**Concentration (mg/kg)**
	1	**2**			**1**	**2**			**1**	**2**		
7	0.12	0.12	0.12	6.05	BDL*	BDL	BDL	BDL	0.80	0.81	0.81	40.31
14	0.10	0.11	0.11	5.38	0.06	BDL	0.04	1.83	0.80	0.80	0.80	40.08
21	0.10	0.10	0.10	5.03	0.06	BDL	0.03	1.70	0.80	0.81	0.81	40.28
28	0.10	0.11	0.11	5.38	BDL	BDL	BDL	BDL	0.88	0.90	0.89	44.55
35	0.09	0.06	0.07	3.70	BDL	BDL	BDL	BDL	0.98	0.97	0.97	48.64
42	0.08	0.05	0.07	3.30	BDL	BDL	BDL	BDL	0.95	0.96	0.96	47.79
49	0.08	0.08	0.08	3.83	BDL	BDL	BDL	BDL	0.98	0.98	0.98	48.83
56	0.06	0.10	0.08	3.80	BDL	BDL	BDL	BDL	0.98	0.97	0.97	48.69
63	0.08	0.04	0.06	2.80	BDL	BDL	BDL	BDL	0.98	0.98	0.98	49.00
70	0.17	0.06	0.12	5.83	0.17	0.16	0.17	8.33	0.97	0.98	0.97	48.61
77	0.15	0.16	0.16	7.78	0.18	0.19	0.18	9.20	1.08	1.09	1.08	54.25
84	0.15	0.14	0.15	7.35	0.07	0.10	0.09	4.33	0.95	0.93	0.94	47.11
91	0.15	0.15	0.15	7.35	0.22	0.24	0.23	11.45	0.92	0.92	0.92	46.21
98	0.14	0.14	0.14	6.95	0.20	0.20	0.20	9.95	0.90	0.90	0.90	45.13
105	0.13	0.14	0.14	6.78	0.40	0.41	0.40	20.18	0.90	0.90	0.90	45.12
112	0.13	0.14	0.13	6.70	0.22	0.16	0.19	9.65	0.88	0.89	0.89	44.36
119	0.12	0.02	0.07	3.55	0.20	0.21	0.21	10.30	0.86	0.87	0.86	43.19
126	BDL	BDL	BDL	BDL	0.19	0.19	0.19	9.63	0.92	0.93	0.92	46.19
133	BDL	BDL	BDL	BDL	0.21	0.21	0.21	10.68	0.95	0.96	0.96	47.79
140	BDL	BDL	BDL	BDL	0.19	0.18	0.18	9.18	0.95	0.96	0.96	47.82

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)
Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-25 The results of the concentration of Cu, Cr and As in fraction 4 (Fe/Mn oxide bound) of compost pile 1 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (µg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	0.22	0.33	0.27	13.73	0.12	0.12	0.12	5.83	ND**	ND	ND	ND
14	0.28	0.27	0.28	13.93	BDL*	BDL	BDL	BDL	11.74	10.34	11.04	0.55
21	0.24	0.25	0.25	12.30	BDL	BDL	BDL	BDL	11.00	10.32	10.66	0.53
28	0.31	0.31	0.31	15.43	BDL	BDL	BDL	BDL	9.35	6.57	7.96	0.40
35	0.30	0.23	0.27	13.30	BDL	BDL	BDL	BDL	15.47	16.88	16.17	0.81
42	0.28	0.17	0.22	11.00	BDL	BDL	BDL	BDL	15.34	14.34	14.84	0.74
49	0.20	0.28	0.24	11.88	0.32	0.11	0.22	10.78	6.43	5.43	5.93	0.30
56	0.25	0.29	0.27	13.68	BDL	BDL	BDL	BDL	7.65	8.86	8.26	0.41
63	0.28	0.32	0.30	15.00	BDL	0.16	0.10	5.05	3.54	5.43	4.49	0.22
70	0.47	0.33	0.40	20.15	0.47	0.43	0.45	22.65	5.30	4.42	4.86	0.24
77	0.33	0.23	0.28	14.03	0.30	0.33	0.32	15.78	3.56	4.20	3.88	0.19
84	0.23	0.43	0.33	16.53	0.42	0.44	0.43	21.48	4.35	4.65	4.50	0.23
91	0.30	0.56	0.43	21.65	0.43	0.22	0.33	16.43	2.33	5.33	3.83	0.19
98	0.44	0.32	0.38	19.15	0.45	0.44	0.45	22.40	0.04	5.43	2.74	0.14
105	0.43	0.36	0.40	19.85	0.41	0.32	0.37	18.28	2.45	6.50	4.48	0.22
112	0.41	0.27	0.34	17.10	0.54	0.07	0.30	15.23	1.40	3.45	2.43	0.12
119	0.39	0.39	0.39	19.68	BDL	BDL	BDL	BDL	2.30	7.65	4.98	0.25
126	0.21	0.23	0.22	11.15	BDL	0.33	0.19	9.38	2.00	2.40	2.20	0.11
133	0.16	0.16	0.16	8.03	0.23	0.16	0.20	9.83	6.30	ND	3.15	0.16
140	0.13	0.11	0.12	6.10	0.17	0.46	0.31	15.70	0.50	ND	0.25	0.01

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)
**Not detectable
Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-26 The results of the concentration of Cu, Cr and As in fraction 4 (Fe/Mn oxide bound) of compost pile 2 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	2.96	1.83	2.39	119.50	3.12	1.97	2.55	127.38	0.02	0.02	0.02	1.05
14	3.00	2.85	2.92	146.23	3.42	3.33	3.38	168.95	0.04	0.03	0.03	1.69
21	2.30	2.32	2.31	115.38	3.19	2.78	2.98	149.18	0.01	0.03	0.02	0.98
28	2.20	2.71	2.46	122.75	4.23	3.69	3.96	198.00	0.04	0.04	0.04	2.08
35	2.69	2.26	2.48	123.78	3.96	4.51	4.23	211.63	0.05	0.05	0.05	2.49
42	2.98	2.99	2.99	149.25	3.64	3.99	3.81	190.65	0.06	0.05	0.06	2.83
49	2.44	2.45	2.45	122.25	3.39	3.38	3.38	169.15	0.04	0.05	0.05	2.37
56	3.20	3.27	3.24	161.80	4.81	4.86	4.84	241.75	0.07	0.07	0.07	3.39
63	3.72	3.66	3.69	184.28	4.18	4.23	4.20	210.23	0.10	0.11	0.10	5.23
70	2.95	2.92	2.94	146.78	2.95	2.92	2.94	146.78	0.14	0.16	0.15	7.47
77	3.19	3.24	3.21	160.63	2.26	2.12	2.19	109.45	0.11	0.15	0.13	6.39
84	3.10	3.10	3.10	154.90	5.05	5.12	5.09	254.30	0.14	0.15	0.15	7.26
91	4.18	4.23	4.20	210.23	4.11	4.02	4.07	203.33	0.11	0.14	0.12	6.10
98	4.09	3.95	4.02	201.15	3.91	3.94	3.93	196.25	0.22	0.23	0.22	11.0
105	3.77	3.77	3.77	188.55	4.88	4.43	4.66	232.85	0.26	0.28	0.27	13.4
112	3.60	3.67	3.63	181.68	1.80	1.44	1.62	80.880	0.20	0.21	0.20	10.0
119	3.56	3.57	3.57	178.35	5.02	5.01	5.02	250.75	0.18	0.20	0.19	9.3
126	3.21	3.20	3.21	160.33	4.22	4.33	4.28	213.75	0.21	0.23	0.22	10.9
133	3.10	3.10	3.10	155.15	3.10	3.00	3.05	152.50	0.21	0.21	0.21	10.3
140	3.00	2.92	2.96	148.05	3.10	3.14	3.12	156.10	0.22	0.21	0.22	10.9

Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-27 The results of the concentration of Cu, Cr and As in fraction 4 (Fe/Mn oxide bound) of compost pile 3 during composting process

Time	**Cu**				**Cr**				**As**			
	Conc. Read (mg/l)		**Average (mg/l)**	**Concentration (mg/kg)**	**Conc. Read (mg/l)**		**Average (mg/l)**	**Concentration (mg/kg)**	**Conc. Read (mg/l)**		**Average (mg/l)**	**Concentration (mg/kg)**
	1	**2**			**1**	**2**			**1**	**2**		
7	3.43	3.62	3.53	176.30	3.50	3.74	3.62	180.85	0.29	0.29	0.29	14.48
14	4.09	4.08	4.08	204.00	6.22	7.32	6.77	338.38	0.29	0.30	0.29	14.71
21	4.09	4.77	4.43	221.60	5.21	5.25	5.23	261.48	0.34	0.34	0.34	17.05
28	5.03	3.90	4.46	223.20	3.95	4.17	4.06	203.00	0.36	0.35	0.35	17.58
35	4.83	3.83	4.33	216.45	6.26	5.37	5.81	290.50	0.32	0.31	0.31	15.55
42	5.11	5.29	5.20	259.88	5.89	3.48	4.68	234.13	0.39	0.41	0.40	19.95
49	5.23	5.31	5.27	263.55	3.94	5.49	4.72	235.75	0.38	0.38	0.38	19.12
56	3.41	8.50	5.95	297.63	6.83	7.19	7.01	350.25	0.37	0.36	0.36	18.07
63	6.57	6.91	6.74	337.00	8.28	7.94	8.11	405.38	0.30	0.31	0.30	15.06
70	8.72	8.34	8.53	426.38	4.74	4.67	4.71	235.28	0.40	0.39	0.39	19.69
77	9.78	9.81	9.79	489.50	3.35	3.02	3.19	159.28	0.38	0.37	0.37	18.66
84	9.65	9.78	9.71	485.63	5.09	5.32	5.20	260.00	0.41	0.44	0.42	21.04
91	8.28	7.94	8.11	405.38	8.28	7.94	8.11	405.38	0.37	0.38	0.37	18.66
98	7.51	7.56	7.53	376.63	8.28	7.94	8.11	405.38	0.49	0.47	0.48	23.96
105	6.15	6.15	6.15	307.38	8.28	7.94	8.11	405.38	0.49	0.50	0.49	24.67
112	6.55	6.47	6.51	325.38	9.94	9.96	9.95	497.50	0.49	0.49	0.49	24.45
119	6.18	6.15	6.16	308.13	10.2	10.7	10.4	521.25	0.47	0.47	0.47	23.40
126	7.23	7.16	7.19	359.63	10.7	11.7	11.2	559.13	0.42	0.43	0.43	21.30
133	5.50	5.56	5.53	276.38	11.0	10.5	10.8	537.50	0.41	0.45	0.43	21.29
140	5.57	5.56	5.57	278.25	9.94	10.0	9.97	498.50	0.43	0.44	0.43	21.66

Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-28 The results of the concentration of Cu, Cr and As in fraction 4 (Fe/Mn oxide bound) of compost pile 4 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	8.01	7.58	7.80	389.75	11.47	10.79	11.13	556.25	0.45	0.44	0.45	22.43
14	8.70	10.07	9.39	469.25	12.20	10.87	11.54	576.75	0.47	0.46	0.46	23.05
21	8.58	7.72	8.15	407.50	9.71	9.59	9.65	482.38	0.51	0.49	0.50	24.75
28	8.63	8.33	8.48	424.00	9.50	10.78	10.14	506.75	0.44	0.47	0.46	22.73
35	9.88	9.67	9.77	488.50	12.19	11.11	11.65	582.50	0.44	0.43	0.44	21.83
42	10.2	9.83	10.00	499.88	10.36	11.38	10.87	543.25	0.52	0.50	0.51	25.51
49	8.05	8.09	8.07	403.50	9.39	8.71	9.05	452.38	0.50	0.50	0.50	24.84
56	8.48	9.62	9.05	452.50	12.34	11.38	11.86	592.88	0.54	0.52	0.53	26.46
63	10.8	10.5	10.63	531.50	12.63	11.99	12.31	615.50	0.55	0.54	0.54	27.16
70	12.0	11.8	11.91	595.63	12.01	11.82	11.91	595.63	0.54	0.55	0.54	27.17
77	14.8	14.8	14.79	739.50	22.61	22.74	22.67	1133.6	0.58	0.58	0.58	28.98
84	14.9	15.1	15.04	752.00	27.33	27.11	27.22	1360.8	0.61	0.62	0.61	30.55
91	12.6	11.9	12.31	615.50	10.21	10.05	10.13	506.38	0.64	0.61	0.63	31.34
98	11.1	11.0	11.09	554.25	10.01	10.45	10.23	511.38	0.67	0.68	0.67	33.54
105	10.1	10.0	10.04	502.00	10.11	10.03	10.07	503.25	0.68	0.70	0.69	34.44
112	10.6	10.6	10.57	528.50	10.39	10.46	10.42	521.13	0.65	0.65	0.65	32.59
119	10.1	10.1	10.07	503.38	10.39	11.11	10.75	537.38	0.61	0.66	0.63	31.68
126	11.2	11.6	11.40	569.75	10.47	14.98	12.72	636.13	0.60	0.61	0.60	30.19
133	7.21	7.82	7.52	375.75	12.11	12.58	12.34	617.00	0.61	0.61	0.61	30.56
140	7.22	7.23	7.22	361.13	14.94	10.02	12.48	623.75	0.61	0.62	0.61	30.55

Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-29 The results of the concentration of Cu, Cr and As in fraction 5 (Organically bound) of compost pile 1 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	0.17	0.17	0.17	8.48	0.20	0.14	0.17	8.38	0.16	0.10	0.13	6.60
14	0.34	0.18	0.26	12.90	0.08	0.27	0.18	8.80	0.14	0.17	0.16	7.83
21	0.12	0.20	0.16	7.90	0.12	BDL*	0.08	3.90	0.13	0.10	0.12	5.84
28	0.22	0.19	0.20	10.23	BDL	BDL	BDL	BDL	0.12	0.11	0.11	5.69
35	0.13	0.13	0.13	6.50	BDL	BDL	BDL	BDL	0.10	0.10	0.10	5.19
42	0.20	0.23	0.21	10.73	BDL	BDL	BDL	BDL	0.15	0.14	0.14	7.02
49	0.20	0.23	0.21	10.60	BDL	BDL	BDL	BDL	0.16	0.16	0.16	8.00
56	0.21	0.17	0.19	9.45	BDL	BDL	BDL	BDL	0.15	0.16	0.15	7.56
63	0.19	0.11	0.15	7.48	BDL	BDL	BDL	BDL	0.12	0.12	0.12	6.04
70	0.15	0.15	0.15	7.58	0.15	0.15	0.15	7.58	0.10	0.10	0.10	4.97
77	0.18	0.19	0.18	9.13	0.29	0.17	0.23	11.45	0.05	0.05	0.05	2.50
84	0.17	0.16	0.17	8.40	0.39	0.33	0.36	17.95	0.05	0.05	0.05	2.67
91	BDL	BDL	BDL	BDL	0.37	0.21	0.29	14.48	0.06	0.06	0.06	3.02
98	BDL	BDL	BDL	BDL	0.27	0.27	0.27	13.25	0.06	0.06	0.06	2.95
105	BDL	BDL	BDL	BDL	0.38	0.39	0.38	19.05	0.01	0.02	0.01	0.65
112	0.29	0.30	0.29	14.68	0.33	0.29	0.31	15.40	0.01	0.01	0.01	0.27
119	BDL	BDL	BDL	BDL	0.33	0.34	0.33	16.70	BDL	BDL	BDL	BDL
126	BDL	BDL	BDL	BDL	0.36	0.36	0.36	18.00	BDL	BDL	BDL	BDL
133	BDL	BDL	BDL	BDL	0.48	0.38	0.43	21.33	BDL	BDL	BDL	BDL
140	BDL	BDL	BDL	BDL	0.45	0.40	0.42	21.10	BDL	BDL	BDL	BDL

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)
Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-30 The results of the concentration of Cu, Cr and As in fraction 5 (Organically bound) of compost pile 2 during composting process

Time	**Cu**				**Cr**				**As**			
	Conc. Read (mg/l)		**Average (mg/l)**	**Concentration (mg/kg)**	**Conc. Read (mg/l)**		**Average (mg/l)**	**Concentration (mg/kg)**	**Conc. Read (mg/l)**		**Average (mg/l)**	**Concentration (mg/kg)**
	1	**2**			**1**	**2**			**1**	**2**		
7	0.54	0.87	0.70	35.08	4.26	4.29	4.28	213.90	0.77	0.77	0.77	38.5
14	1.35	0.48	0.91	45.68	4.21	3.94	4.08	203.75	0.68	0.62	0.65	32.3
21	0.28	0.61	0.45	22.35	2.48	2.35	2.42	120.83	0.22	0.25	0.23	11.6
28	1.35	0.15	0.75	37.33	1.72	3.78	2.75	137.50	0.21	0.22	0.21	10.6
35	1.15	1.06	1.10	55.13	3.37	3.43	3.40	170.03	0.18	0.18	0.18	9.03
42	0.98	1.67	1.33	66.28	3.38	2.15	2.77	138.28	0.19	0.20	0.20	9.80
49	0.83	1.86	1.34	67.15	2.98	2.92	2.95	147.33	0.20	0.20	0.20	10.1
56	1.00	1.52	1.26	62.90	3.24	2.99	3.12	155.78	0.19	0.18	0.19	9.27
63	0.46	1.43	0.95	47.43	3.23	3.18	3.21	160.30	0.17	0.17	0.17	8.63
70	0.97	0.98	0.97	48.53	3.97	3.98	3.97	198.53	0.14	0.15	0.14	7.15
77	0.78	0.78	0.78	38.95	3.56	3.67	3.62	180.73	0.10	0.11	0.11	5.25
84	1.29	1.27	1.28	64.05	3.58	3.44	3.51	175.63	0.11	0.11	0.11	5.28
91	1.22	1.22	1.22	61.15	3.43	3.58	3.50	175.05	0.12	0.12	0.12	5.93
98	1.32	1.35	1.34	66.88	3.23	3.25	3.24	161.98	0.12	0.13	0.12	6.15
105	1.22	1.12	1.17	58.45	3.11	3.10	3.11	155.30	0.09	0.09	0.09	4.63
112	1.11	1.11	1.11	55.53	4.54	4.51	4.53	226.38	0.07	0.07	0.07	3.53
119	1.33	1.34	1.33	66.60	3.67	3.79	3.73	186.43	0.09	0.09	0.09	4.27
126	1.49	1.60	1.54	77.13	4.66	4.78	4.72	235.93	0.02	0.03	0.03	1.26
133	1.66	1.77	1.72	85.73	4.53	4.59	4.56	227.98	0.01	0.01	0.01	0.71
140	2.00	2.00	2.00	99.95	4.78	4.89	4.83	241.65	0.02	0.02	0.02	0.88

Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-31 The results of the concentration of Cu, Cr and As in fraction 5 (Organically bound) of compost pile 3 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	1.60	1.29	1.45	72.23	5.75	8.08	6.91	345.63	1.05	1.02	1.04	51.86
14	1.67	1.57	1.62	80.83	4.61	3.69	4.15	207.38	0.79	0.84	0.81	40.60
21	0.98	1.31	1.14	57.10	5.08	5.05	5.07	253.43	0.42	0.43	0.43	21.24
28	1.52	1.58	1.55	77.58	4.49	4.43	4.46	223.00	0.41	0.45	0.43	21.63
35	1.43	1.30	1.37	68.25	4.62	3.62	4.12	206.05	0.32	0.32	0.32	15.92
42	1.93	1.89	1.91	95.35	3.25	2.57	2.91	145.50	0.34	0.33	0.34	16.93
49	1.54	1.52	1.53	76.50	2.25	3.57	2.91	145.38	0.36	0.33	0.35	17.27
56	3.20	3.19	3.20	159.73	3.92	3.07	3.50	174.73	0.31	0.34	0.32	16.19
63	4.47	4.56	4.52	225.90	4.50	3.99	4.24	212.13	0.26	0.27	0.26	13.05
70	8.52	8.49	8.51	425.25	8.52	8.49	8.51	425.25	0.22	0.22	0.22	11.11
77	10.78	10.77	10.77	538.63	16.42	16.23	16.32	816.13	0.17	0.18	0.18	8.76
84	8.84	8.87	8.85	442.63	17.78	17.71	17.74	887.13	0.21	0.20	0.20	10.20
91	8.27	8.33	8.30	415.00	17.11	17.15	17.13	856.25	0.19	0.19	0.19	9.50
98	7.84	7.79	7.81	390.50	15.51	15.04	15.28	763.75	0.21	0.21	0.21	10.30
105	7.44	7.61	7.52	376.00	15.74	15.46	15.60	780.00	0.15	0.16	0.16	7.85
112	5.78	5.75	5.76	288.13	13.19	14.49	13.84	691.75	0.16	0.17	0.16	8.05
119	9.96	10.01	9.98	499.13	14.45	14.71	14.58	728.75	0.14	0.15	0.14	7.03
126	8.23	7.67	7.95	397.38	15.01	15.50	15.25	762.50	0.08	0.08	0.08	3.85
133	8.89	8.83	8.86	442.88	14.99	15.56	15.28	763.75	0.06	0.06	0.06	3.08
140	7.23	7.81	7.52	375.88	16.07	16.68	16.37	818.63	0.06	0.06	0.06	3.12

Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-32 The results of the concentration of Cu, Cr and As in fraction 5 (Organically bound) of compost pile 4 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	3.43	2.37	2.90	145.03	14.78	14.88	14.83	741.50	1.11	1.15	1.13	56.5
14	2.56	2.53	2.54	127.00	14.22	13.62	13.92	695.88	0.98	1.01	0.99	49.7
21	2.11	2.48	2.30	114.75	13.86	13.16	13.51	675.38	0.78	0.84	0.81	40.5
28	2.52	2.49	2.51	125.28	12.14	12.87	12.50	625.13	0.70	0.73	0.71	35.6
35	4.36	4.31	4.34	216.73	8.34	4.63	6.48	324.00	0.44	0.35	0.39	19.7
42	3.37	4.37	3.87	193.43	6.53	6.79	6.66	332.75	0.47	0.37	0.42	21.0
49	4.93	4.56	4.74	237.20	8.52	8.39	8.46	422.75	0.45	0.41	0.43	21.4
56	5.00	5.00	5.00	249.83	9.46	8.27	8.86	443.13	0.39	0.37	0.38	18.9
63	7.33	9.74	8.53	426.63	9.59	9.16	9.38	468.75	0.38	0.36	0.37	18.5
70	10.01	9.79	9.90	495.00	10.01	9.79	9.90	495.00	0.36	0.37	0.36	18.1
77	12.87	12.61	12.74	637.00	16.13	17.34	16.73	836.50	0.25	0.25	0.25	12.4
84	15.26	15.33	15.29	764.50	17.94	17.74	17.84	891.88	0.26	0.27	0.26	13.2
91	14.99	14.86	14.92	746.00	17.77	17.79	17.78	889.00	0.23	0.23	0.23	11.5
98	12.71	12.81	12.76	637.75	18.96	19.46	19.21	960.38	0.25	0.26	0.26	12.7
105	9.59	9.16	9.38	468.75	20.01	21.28	20.65	1032.2	0.21	0.21	0.21	10.3
112	8.07	8.08	8.07	403.50	21.61	21.79	21.70	1085.0	0.20	0.20	0.20	9.83
119	11.70	12.01	11.85	592.50	20.60	20.88	20.74	1037.0	0.22	0.22	0.22	10.9
126	11.15	11.51	11.33	566.25	20.05	19.38	19.71	985.63	0.17	0.17	0.17	8.37
133	13.31	13.26	13.28	664.00	19.95	20.79	20.37	1018.4	0.11	0.11	0.11	5.39
140	12.74	13.00	12.87	643.50	21.68	21.08	21.38	1068.9	0.10	0.10	0.10	5.01

Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-33 The results of the concentration of Cu, Cr and As in fraction 6 (Residual) of compost pile 1 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	BDL	0.13	0.07	3.53	BDL	BDL	BDL	BDL	0.02	0.05	0.03	1.67
14	0.09	0.10	0.09	4.65	BDL	BDL	BDL	BDL	0.02	0.04	0.03	1.33
21	0.11	0.09	0.10	5.15	BDL	BDL	BDL	BDL	0.19	0.16	0.17	8.68
28	0.12	BDL	0.08	4.18	BDL	BDL	BDL	BDL	0.18	0.16	0.17	8.39
35	0.19	BDL	0.09	4.68	BDL	BDL	BDL	BDL	0.19	0.18	0.18	9.08
42	BDL	0.17	0.08	4.20	BDL	BDL	BDL	BDL	0.13	0.12	0.13	6.35
49	0.17	BDL	0.09	4.28	BDL	BDL	BDL	BDL	0.15	0.15	0.15	7.68
56	0.19	0.13	0.16	8.13	BDL	BDL	BDL	BDL	0.14	0.15	0.15	7.29
63	0.06	0.09	0.08	3.78	BDL	BDL	BDL	BDL	0.10	0.14	0.12	5.97
70	0.27	0.25	0.26	13.08	0.27	0.25	0.26	13.08	0.16	0.17	0.16	8.06
77	0.30	0.30	0.30	14.98	0.19	0.22	0.20	10.20	0.13	0.16	0.14	7.14
84	0.18	0.17	0.18	8.83	0.14	0.14	0.14	6.83	0.10	0.11	0.10	5.19
91	0.17	0.16	0.17	8.23	0.11	0.15	0.13	6.43	0.15	0.15	0.15	7.56
98	0.14	0.14	0.14	7.05	0.16	0.17	0.17	8.28	0.09	0.08	0.09	4.29
105	0.17	0.16	0.16	8.15	0.15	0.16	0.16	7.78	0.11	0.10	0.10	5.14
112	0.18	0.17	0.17	8.55	0.17	0.25	0.21	10.65	0.16	0.15	0.16	7.84
119	0.15	0.15	0.15	7.35	0.23	0.22	0.23	11.38	0.14	0.13	0.14	6.81
126	0.17	0.17	0.17	8.53	0.34	0.32	0.33	16.58	0.16	0.16	0.16	8.07
133	0.18	0.19	0.19	9.25	0.22	0.28	0.25	12.48	0.18	0.16	0.17	8.52
140	0.17	0.18	0.18	8.90	0.17	0.28	0.22	11.03	0.15	0.16	0.16	7.87

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)
Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-34 The results of the concentration of Cu, Cr and As in fraction 6 (Residual) of compost pile 2 during composting process

Time	**Cu**				**Cr**				**As**			
	Conc. Read (mg/l)		**Average (mg/l)**	**Concentration (mg/kg)**	**Conc. Read (mg/l)**		**Average (mg/l)**	**Concentration (mg/kg)**	**Conc. Read (mg/l)**		**Average (mg/l)**	**Concentration (mg/kg)**
	1	**2**			**1**	**2**			**1**	**2**		
7	BDL*	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.14	0.06	0.10	4.89
14	BDL	0.13	0.06	3.18	BDL	BDL	BDL	BDL	0.11	0.20	0.15	7.63
21	BDL	0.08	0.04	1.93	1.77	0.06	0.92	45.90	0.22	0.18	0.20	10.03
28	0.52	0.21	0.36	18.13	0.79	1.32	1.06	52.83	0.23	0.16	0.19	9.62
35	0.45	0.32	0.39	19.28	1.64	0.93	1.28	64.20	0.22	0.23	0.23	11.23
42	0.31	0.98	0.64	32.10	0.86	1.84	1.35	67.53	0.24	0.18	0.21	10.56
49	1.21	1.25	1.23	61.63	0.83	0.89	0.86	43.13	0.27	0.30	0.29	14.32
56	1.10	0.99	1.04	52.15	3.08	2.87	2.98	148.75	0.31	0.28	0.29	14.68
63	1.17	1.19	1.18	58.95	3.20	3.21	3.20	160.18	0.35	0.34	0.34	17.10
70	1.34	1.34	1.34	66.93	2.32	2.28	2.30	115.00	0.38	0.38	0.38	18.92
77	1.67	1.67	1.67	83.58	3.24	3.29	3.27	163.28	0.46	0.46	0.46	22.90
84	1.45	1.53	1.49	74.48	2.01	2.43	2.22	111.00	0.51	0.51	0.51	25.45
91	1.89	1.88	1.89	94.28	3.20	3.21	3.20	160.18	0.51	0.52	0.52	25.82
98	1.99	1.99	1.99	99.55	3.22	3.42	3.32	166.15	0.59	0.58	0.59	29.29
105	1.77	1.88	1.82	91.20	3.09	3.00	3.04	152.15	0.61	0.63	0.62	30.87
112	2.00	2.00	2.00	99.80	5.06	5.04	5.05	252.43	0.69	0.70	0.70	34.88
119	1.53	1.56	1.55	77.25	4.92	4.99	4.95	247.70	0.68	0.68	0.68	34.04
126	1.79	1.77	1.78	89.08	3.99	4.01	4.00	200.15	0.70	0.71	0.70	35.14
133	2.00	2.00	2.00	100.03	4.01	4.02	4.01	200.63	0.68	0.68	0.68	34.10
140	2.11	2.44	2.28	113.73	4.17	4.23	4.20	209.90	0.72	0.71	0.71	35.58

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)
Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-35 The results of the concentration of Cu, Cr and As in fraction 6 (Residual) of compost pile 3 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	BDL*	0.22	0.11	5.40	BDL	0.28	0.14	7.05	0.15	0.14	0.15	7.26
14	0.70	0.37	0.53	26.68	2.27	1.25	1.76	88.08	0.30	0.26	0.28	13.96
21	0.75	BDL	0.38	18.78	1.71	2.03	1.87	93.55	0.37	0.32	0.35	17.29
28	1.22	0.71	0.96	48.13	3.30	3.45	3.37	168.68	0.31	0.32	0.32	15.91
35	1.43	1.11	1.27	63.28	3.19	2.74	2.97	148.25	0.33	0.32	0.33	16.29
42	1.35	2.22	1.78	89.20	3.73	3.60	3.67	183.28	0.31	0.38	0.34	17.18
49	1.97	1.99	1.98	99.00	4.49	4.15	4.32	215.88	0.30	0.30	0.30	15.11
56	2.79	2.94	2.86	143.03	3.45	2.80	3.13	156.25	0.37	0.36	0.36	18.04
63	2.86	2.84	2.85	142.38	6.52	2.77	4.64	232.13	0.46	0.41	0.44	21.84
70	3.14	3.10	3.12	155.88	3.14	3.10	3.12	155.88	0.51	0.50	0.50	25.11
77	3.82	4.34	4.08	203.88	5.24	5.22	5.23	261.60	0.51	0.50	0.51	25.28
84	4.35	4.40	4.38	218.75	11.70	11.56	11.63	581.38	0.60	0.60	0.60	30.17
91	3.86	3.90	3.88	193.88	11.16	11.05	11.10	555.00	0.70	0.67	0.68	34.22
98	3.39	3.56	3.48	173.75	11.52	11.63	11.57	578.63	0.75	0.75	0.75	37.33
105	2.79	3.01	2.90	144.75	11.53	11.52	11.52	576.13	0.79	0.79	0.79	39.51
112	3.06	2.96	3.01	150.38	13.59	13.49	13.54	676.88	0.87	0.86	0.87	43.33
119	3.34	3.92	3.63	181.25	13.50	13.65	13.57	678.63	0.88	0.88	0.88	44.03
126	4.41	4.41	4.41	220.38	12.83	12.71	12.77	638.50	0.89	0.90	0.90	44.73
133	3.61	3.77	3.69	184.38	13.02	12.98	13.00	649.88	0.88	0.88	0.88	44.07
140	2.96	3.37	3.16	158.13	12.94	12.93	12.93	646.63	0.90	0.91	0.90	45.08

*Below Detection Limit (As = 0.001 mg/L, Cr = 0.06 mg/L, Cu = 0.05 mg/L)

Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-36 The results of the concentration of Cu, Cr and As in fraction 6 (Residual) of compost pile 4 during composting process

Time	Cu				Cr				As			
	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)	Conc. Read (mg/l)		Average (mg/l)	Concentration (mg/kg)
	1	2			1	2			1	2		
7	0.09	0.50	0.30	14.93	1.14	2.86	2.00	99.78	0.33	0.34	0.33	16.70
14	0.58	0.93	0.76	37.75	3.33	3.12	3.23	161.40	0.37	0.35	0.36	17.76
21	1.09	0.88	0.98	49.18	4.76	4.57	4.66	233.13	0.40	0.35	0.37	18.71
28	1.60	1.67	1.64	81.80	6.26	6.57	6.41	320.63	0.38	0.35	0.37	18.33
35	3.63	3.66	3.65	182.33	9.29	9.64	9.46	473.13	0.37	0.41	0.39	19.60
42	3.67	3.58	3.63	181.33	7.05	7.91	7.48	374.00	0.42	0.41	0.41	20.69
49	3.53	3.56	3.54	177.13	9.84	9.16	9.50	475.00	0.46	0.49	0.48	23.81
56	4.41	4.42	4.42	220.73	10.34	10.60	10.47	523.38	0.56	0.49	0.53	26.32
63	4.59	4.58	4.59	229.23	10.65	10.59	10.62	530.88	0.60	0.59	0.60	29.78
70	5.87	5.06	5.46	273.13	9.87	10.06	9.96	498.13	0.62	0.62	0.62	31.22
77	9.77	9.65	9.71	485.38	14.29	13.95	14.12	706.00	0.71	0.71	0.71	35.28
84	10.45	10.00	10.23	511.25	13.88	13.84	13.86	692.75	0.73	0.73	0.73	36.61
91	10.01	9.97	9.99	499.25	13.93	13.71	13.82	691.00	0.81	0.81	0.81	40.33
98	9.95	9.97	9.96	497.88	13.42	13.51	13.46	673.00	0.85	0.85	0.85	42.50
105	8.90	9.00	8.95	447.38	15.61	15.96	15.78	789.13	0.90	0.92	0.91	45.53
112	8.50	7.52	8.01	400.38	15.58	15.59	15.58	779.13	0.95	0.95	0.95	47.38
119	8.33	8.38	8.35	417.50	15.01	14.55	14.78	738.75	0.96	0.96	0.96	48.06
126	10.00	10.01	10.00	500.13	14.97	14.56	14.76	738.13	1.00	1.00	1.00	49.96
133	9.99	9.42	9.71	485.25	14.36	13.88	14.12	706.00	0.95	0.96	0.96	47.74
140	9.41	9.06	9.24	461.75	14.41	14.01	14.21	710.38	1.00	0.95	0.98	48.80

Note. Using 1 g of samples and dilute the digested sample into 50 ml volumetric flask

Table B-37 The total concentrations of Cu, Cr, and As in soil and soils amended compost during planting.

Type of soils	Days	Concentration of Cu (mg/kg)		
		Cu	Cr	As
Soil amended compost from pile 1	0	49.60	44.50	35.66
	15	44.30	44.30	44.33
	30	46.60	41.40	41.45
	45	48.10	43.00	29.04
Soil amended compost from pile 2	0	340.0	600.30	247.45
	15	342.7	600.20	231.76
	30	319.1	575.70	239.67
	45	325.9	595.00	241.99
Soil amended compost from pile 3	0	901.8	1701.0	557.10
	15	802.4	1665.4	523.62
	30	791.8	1525.9	539.89
	45	857.3	1612.8	546.00
Soil amended compost from pile 4	0	1447.0	2130.5	700.34
	15	1202.4	2202.4	713.78
	30	1191.8	1991.8	689.00
	45	1370.2	2171.0	679.02
Soil control	0	17.00	22.00	11.35
	15	17.20	24.30	12.67
	30	18.20	25.70	13.47
	45	15.30	30.30	15.55

Table B-38 The concentrations of Cu in soil and soils amended compost during planting.

Type of soils	Days	Concentration of Cu (mg/kg)					
		F1	F2	F3	F4	F5	F6
Soil amended compost from pile 1	0	0.99	0.98	0.12	16.7	17.38	13.48
	15	0.88	2.80	0.30	14.6	19.80	7.18
	30	0.64	1.55	0.23	12.7	20.08	8.88
	45	0.55	2.23	0.53	3.83	25.40	9.63
Soil amended compost from pile 2	0	7.43	1.43	0.08	137.6	124.6	96.88
	15	7.18	1.38	1.10	113.2	145.1	72.13
	30	6.08	1.00	1.13	72.13	154.8	65.25
	45	4.63	0.65	1.75	43.90	187.0	49.83
Soil amended compost from pile 3	0	11.5	3.90	2.83	352.1	357.8	178.4
	15	10.8	2.70	3.98	203.1	472.5	99.18
	30	9.35	1.40	5.28	150.2	585.3	81.88
	45	9.75	1.25	13.4	106.7	600.7	78.35
Soil amended compost from pile 4	0	29.9	12.6	1.45	613.9	382.3	316.4
	15	20.8	11.3	18.6	586.2	523.7	225.3
	30	18.8	10.8	23.9	302.4	641.8	175.7
	45	17.2	9.23	25.5	224.9	766.1	163.5
Soil control	0	ND*	0.19	ND	4.93	10.58	0.80
	15	ND	0.10	ND	5.28	10.20	3.60
	30	ND	0.09	ND	1.43	9.43	6.28
	45	ND	0.02	ND	2.33	8.63	5.10

*ND = Not detectable

Table B-39 The concentrations of Cr in soil and soils amended compost during planting.

Type of soils	Days	Concentration of Cr (mg/kg)					
		F1	F2	F3	F4	F5	F6
Soil amended compost from pile 1	0	0.075	ND*	0.005	16.300	15.125	8.250
	15	0.068	ND	0.012	11.775	22.750	2.925
	30	0.060	ND	0.023	11.250	24.250	1.900
	45	0.042	ND	0.021	14.000	23.575	0.573
Soil amended compost from pile 2	0	1.234	ND	7.860	342.35	245.90	94.700
	15	1.094	ND	4.860	231.77	259.20	64.250
	30	0.998	ND	3.160	221.85	294.85	32.975
	45	0.834	ND	5.908	113.52	339.27	22.775
Soil amended compost from pile 3	0	14.35	0.001	12.43	771.94	650.90	311.25
	15	12.65	0.004	13.40	669.22	706.35	199.85
	30	16.04	ND	12.55	531.95	730.57	206.97
	45	10.99	ND	10.98	470.52	788.75	161.17
Soil amended compost from pile 4	0	33.45	ND	21.77	1039.3	745.10	524.17
	15	32.17	0.094	23.45	1007.5	800.30	418.07
	30	28.66	0.043	22.87	766.92	919.10	311.47
	45	25.77	0.060	20.54	625.17	928.35	210.52
Soil control	0	ND	ND	ND	26.975	0.300	3.100
	15	ND	ND	ND	22.600	ND	2.125
	30	ND	ND	ND	27.600	ND	1.650
	45	ND	ND	ND	25.450	ND	ND

*ND = Not detectable

Table B-40 The concentrations of As in soil and soils amended compost during planting.

Type of soils	Days	Concentration of As (mg/kg)					
		F1	F2	F3	F4	F5	F6
Soil amended compost from pile 1	0	10.03	5.34	0.64	13.28	2.18	2.03
	15	11.04	3.78	1.01	15.25	2.56	1.21
	30	9.03	6.90	0.55	18.38	3.06	ND*
	45	5.02	4.27	0.49	18.62	3.49	ND
Soil amended compost from pile 2	0	124.0	51.95	24.78	33.15	3.62	14.58
	15	115.1	42.07	6.75	47.56	4.01	8.95
	30	94.57	39.48	5.08	59.30	5.05	13.22
	45	82.93	41.07	24.90	70.74	5.87	15.56
Soil amended compost from pile 3	0	175.0	133.1	118.3	89.93	4.08	16.55
	15	140.2	133.4	109.9	85.68	6.44	17.67
	30	138.8	142.7	129.3	98.44	8.68	18.67
	45	84.42	151.7	130.1	129.5	9.31	15.89
Soil amended compost from pile 4	0	209.0	183.8	169.8	114.9	12.67	20.33
	15	213.7	174.3	154.2	115.9	19.04	21.43
	30	162.7	173.1	182.2	154.7	12.14	13.24
	45	118.7	182.1	179.9	167.6	13.95	19.77
Soil control	0	0.56	ND	0.57	9.03	1.85	1.59
	15	0.43	ND	0.76	6.59	2.07	1.71
	30	0.19	ND	0.44	7.14	2.50	1.22
	45	0.69	ND	0.16	6.77	2.76	1.68

*ND = Not detectable

Table B-41 The results of plant growth

Type of soils	Days	Parameters				
		Length			Fresh weight	Dry weight
		Root	Trunk	Leave		
Soil amended compost from pile 1	0	0.00	0.00	0.00	0.00	0.00
	15	2.80	1.30	1.70	0.08	0.02
	30	6.80	1.80	7.50	1.26	0.20
	45	25.6	2.00	18.7	27.5	2.05
Soil amended compost from pile 2	0	0.00	0.00	0.00	0.00	0.00
	15	3.10	1.10	1.80	0.09	0.04
	30	6.30	2.00	8.20	0.88	0.09
	45	37.5	2.50	20.9	34.7	2.36
Soil amended compost from pile 3	0	0.00	0.00	0.00	0.00	0.00
	15	4.10	1.40	1.50	0.06	0.01
	30	7.10	1.50	5.60	0.95	0.07
	45	20.4	1.70	16.7	22.5	2.03
Soil amended compost from pile 4	0	0.00	0.00	0.00	0.00	0.00
	15	2.30	0.80	1.10	0.02	0.00
	30	5.20	1.10	5.30	0.89	0.08
	45	14.4	2.00	14.5	18.34	1.66
Soil control	0	0.00	0.00	0.00	0.00	0.00
	15	2.41	1.68	4.07	0.32	0.09
	30	9.10	1.90	7.12	1.60	0.22
	45	17.5	3.00	17.5	15.8	1.24

APPENDIX C

STATISTICAL DATA

Results of temperature of all compost piles

One-way ANOVA: temp 1, temp 2, temp 3, temp 4

```
Source   DF     SS   MS     F      P
Factor    3    422  141  1.36  0.253
Error   620  64037  103
Total   623  64459

S = 10.16   R-Sq = 0.66%   R-Sq(adj) = 0.17%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level     N   Mean  StDev  ---+---------+---------+---------+------
temp 1  156  36.15  10.17              (----------*----------)
temp 2  156  34.17   9.56  (----------*----------)
temp 3  156  36.01  10.31             (----------*----------)
temp 4  156  34.82  10.58      (---------*----------)
                           ---+---------+---------+---------+------
                           33.0      34.5      36.0      37.5

Pooled StDev = 10.16

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons

Individual confidence level = 98.95%

temp 1 subtracted from:

        Lower  Center  Upper   +---------+---------+---------+---------
temp 2  -4.92   -1.97   0.98   (-----------*-----------)
temp 3  -3.09   -0.14   2.81         (----------*-----------)
temp 4  -4.28   -1.32   1.63      (-----------*-----------)
                               +---------+---------+---------+---------
                             -5.0      -2.5       0.0       2.5

temp 2 subtracted from:

        Lower  Center  Upper   +---------+---------+---------+---------
temp 3  -1.12    1.83   4.78               (----------*-----------)
temp 4  -2.31    0.65   3.60            (-----------*----------)
                               +---------+---------+---------+---------
                             -5.0      -2.5       0.0       2.5

temp 3 subtracted from:

        Lower  Center  Upper   +---------+---------+---------+---------
temp 4  -4.14   -1.18   1.77      (-----------*-----------)
                               +---------+---------+---------+---------
                             -5.0      -2.5       0.0       2.5
```

Results of pH of all compost piles

One-way ANOVA: pH1, pH2, pH3, pH4

```
Source  DF      SS      MS     F      P
Factor   3  0.1597  0.0532  0.68  0.570
Error   80  6.3031  0.0788
Total   83  6.4628

S = 0.2807   R-Sq = 2.47%   R-Sq(adj) = 0.00%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level   N    Mean   StDev  ----+---------+---------+---------+-----
pH1    21  7.9338  0.2342      (-----------*------------)
pH2    21  8.0052  0.3315            (------------*-----------)
pH3    21  7.9524  0.2888        (-----------*-----------)
pH4    21  7.8833  0.2588  (-----------*------------)
                           ----+---------+---------+---------+-----
                             7.80      7.90      8.00      8.10

Pooled StDev = 0.2807

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons

Individual confidence level = 98.96%

pH1 subtracted from:

      Lower   Center   Upper  -------+---------+---------+---------+--
pH2  -0.1558   0.0714  0.2987          (-----------*----------)
pH3  -0.2087   0.0186  0.2458        (----------*----------)
pH4  -0.2777  -0.0505  0.1768    (----------*-----------)
                              -------+---------+---------+---------+--
                                   -0.20      0.00      0.20      0.40

pH2 subtracted from:

      Lower   Center   Upper  -------+---------+---------+---------+--
pH3  -0.2801  -0.0529  0.1744    (----------*-----------)
pH4  -0.3492  -0.1219  0.1053  (----------*----------)
                              -------+---------+---------+---------+--
                                   -0.20      0.00      0.20      0.40

pH3 subtracted from:

      Lower   Center   Upper  -------+---------+---------+---------+--
pH4  -0.2963  -0.0690  0.1582    (-----------*----------)
                              -------+---------+---------+---------+--
                                   -0.20      0.00      0.20      0.40
```

Results of moisture content of all compost piles

One-way ANOVA: MC1, MC2, MC3, MC4

```
Source  DF      SS     MS     F      P
Factor   3  100.88  33.63  7.68  0.000
Error   80  350.36   4.38
Total   83  451.24

S = 2.093   R-Sq = 22.36%   R-Sq(adj) = 19.44%

                        Individual 95% CIs For Mean Based on
                        Pooled StDev
Level   N    Mean  StDev  --+---------+---------+---------+-------
MC1    21  58.479  2.330                  (------*-------)
MC2    21  58.499  1.908                  (------*-------)
MC3    21  57.206  1.868            (-------*------)
MC4    21  55.838  2.227  (------*-------)
                          --+---------+---------+---------+-------
                          55.2      56.4      57.6      58.8

Pooled StDev = 2.093

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons

Individual confidence level = 98.96%

MC1 subtracted from:

     Lower  Center   Upper  -------+---------+---------+---------+--
MC2  -1.675   0.020   1.714           (------*------)
MC3  -2.967  -1.273   0.421      (------*------)
MC4  -4.335  -2.641  -0.947  (-----*------)
                            -------+---------+---------+---------+--
                                -2.5       0.0       2.5       5.0

MC2 subtracted from:

     Lower  Center   Upper  -------+---------+---------+---------+--
MC3  -2.987  -1.292   0.402      (------*------)
MC4  -4.355  -2.660  -0.966  (-----*------)
                            -------+---------+---------+---------+--
                                -2.5       0.0       2.5       5.0

MC3 subtracted from:

     Lower  Center  Upper  -------+---------+---------+---------+--
MC4  -3.062  -1.368  0.326      (------*-----)
                           -------+---------+---------+---------+--
                               -2.5       0.0       2.5       5.0
```

Results of total volatile solids of all compost piles

One-way ANOVA: TVS1, TVS2, TVS3, TVS4

```
Source  DF     SS   MS     F      P
Factor   3    373  124  0.56  0.642
Error   80  17709  221
Total   83  18082

S = 14.88   R-Sq = 2.06%   R-Sq(adj) = 0.00%

                       Individual 95% CIs For Mean Based on
                       Pooled StDev
Level   N   Mean  StDev  ----+---------+---------+---------+-----
TVS1   21  44.65  15.33  (------------*------------)
TVS2   21  49.92  13.50           (------------*------------)
TVS3   21  49.03  14.10          (------------*------------)
TVS4   21  46.31  16.42      (------------*------------)
                       ----+---------+---------+---------+-----
                        40.0      45.0      50.0      55.0

Pooled StDev = 14.88

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons

Individual confidence level = 98.96%

TVS1 subtracted from:

       Lower  Center  Upper  ------+---------+---------+---------+---
TVS2   -6.77    5.27  17.32          (-----------*-----------)
TVS3   -7.66    4.38  16.43         (-----------*-----------)
TVS4  -10.38    1.66  13.71        (-----------*-----------)
                             ------+---------+---------+---------+---
                                 -10         0        10        20

TVS2 subtracted from:

       Lower  Center  Upper  ------+---------+---------+---------+---
TVS3  -12.94   -0.89  11.15     (-----------*-----------)
TVS4  -15.66   -3.61   8.43  (-----------*-----------)
                             ------+---------+---------+---------+---
                                 -10         0        10        20

TVS3 subtracted from:

       Lower  Center  Upper  ------+---------+---------+---------+---
TVS4  -14.77   -2.72   9.32  (-----------*-----------)
                             ------+---------+---------+---------+---
                                 -10         0        10        20
```

Results of total organic carbon of all compost piles

One-way ANOVA: TOC1, TOC2, TOC3, TOC4

```
Source  DF      SS    MS     F      P
Factor   3    73.4  24.5  0.39  0.764
Error   80  5079.6  63.5
Total   83  5152.9

S = 7.968   R-Sq = 1.42%   R-Sq(adj) = 0.00%

                        Individual 95% CIs For Mean Based on
                        Pooled StDev
Level   N    Mean  StDev   -+---------+---------+---------+--------
TOC1   21  25.814  8.444   (-------------*-------------)
TOC2   21  27.905  7.301          (-------------*------------)
TOC3   21  27.548  7.465         (-------------*-------------)
TOC4   21  25.938  8.582    (-------------*-------------)
                           -+---------+---------+---------+--------
                          22.5      25.0      27.5      30.0

Pooled StDev = 7.968

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons

Individual confidence level = 98.96%

TOC1 subtracted from:

       Lower  Center  Upper  -------+---------+---------+---------+--
TOC2  -4.361   2.090  8.542        (------------*------------)
TOC3  -4.718   1.733  8.184        (-----------*------------)
TOC4  -6.327   0.124  6.575     (------------*------------)
                             -------+---------+---------+---------+--
                                 -5.0       0.0       5.0      10.0

TOC2 subtracted from:

       Lower  Center  Upper  -------+---------+---------+---------+--
TOC3  -6.808  -0.357  6.094     (------------*------------)
TOC4  -8.418  -1.967  4.484  (------------*------------)
                             -------+---------+---------+---------+--
                                 -5.0       0.0       5.0      10.0

TOC3 subtracted from:

       Lower  Center  Upper  -------+---------+---------+---------+--
TOC4  -8.061  -1.610  4.842   (------------*------------)
                             -------+---------+---------+---------+--
                                 -5.0       0.0       5.0      10.0
```

Results of total nitrogen of all compost piles

One-way ANOVA: TN1, TN2, TN3, TN4

```
Source  DF       SS       MS     F      P
Factor   3  0.02711  0.00904  2.37  0.077
Error   80  0.30511  0.00381
Total   83  0.33222

S = 0.06176   R-Sq = 8.16%   R-Sq(adj) = 4.72%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level   N    Mean   StDev  ---+---------+---------+---------+------
TN1    21  1.5043  0.0861              (--------*--------)
TN2    21  1.4576  0.0411  (--------*--------)
TN3    21  1.4838  0.0453        (--------*--------)
TN4    21  1.4981  0.0640           (--------*--------)
                           ---+---------+---------+---------+------
                            1.440     1.470     1.500     1.530

Pooled StDev = 0.0618

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons

Individual confidence level = 98.96%

TN1 subtracted from:

        Lower    Center    Upper  ---------+---------+---------+---------+
TN2  -0.09666  -0.04667  0.00333  (---------*---------)
TN3  -0.07047  -0.02048  0.02952      (---------*---------)
TN4  -0.05619  -0.00619  0.04381        (---------*---------)
                                  ---------+---------+---------+---------+
                                      -0.050     0.000     0.050     0.100

TN2 subtracted from:

        Lower   Center    Upper  ---------+---------+---------+---------+
TN3  -0.02381  0.02619  0.07619             (---------*---------)
TN4  -0.00952  0.04048  0.09047               (---------*---------)
                                 ---------+---------+---------+---------+
                                     -0.050     0.000     0.050     0.100

TN3 subtracted from:

        Lower   Center    Upper  ---------+---------+---------+---------+
TN4  -0.03571  0.01429  0.06428           (---------*---------)
                                 ---------+---------+---------+---------+
                                     -0.050     0.000     0.050     0.100
```

Results of C/N ratio of all compost piles

One-way ANOVA: CN1, CN2, CN3, CN4

```
Source  DF      SS    MS     F      P
Factor   3    67.7  22.6  0.93  0.432
Error   80  1946.6  24.3
Total   83  2014.2

S = 4.933   R-Sq = 3.36%   R-Sq(adj) = 0.00%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level   N    Mean  StDev  ------+---------+---------+---------+---
CN1    21  16.990  4.701  (----------*----------)
CN2    21  19.153  4.955           (----------*---------)
CN3    21  18.526  4.842        (----------*---------)
CN4    21  17.227  5.218   (----------*----------)
                          ------+---------+---------+---------+---
                              16.0      18.0      20.0      22.0

Pooled StDev = 4.933

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons

Individual confidence level = 98.96%

CN1 subtracted from:

     Lower  Center  Upper  -------+---------+---------+---------+--
CN2  -1.830   2.163  6.157            (----------*-----------)
CN3  -2.457   1.537  5.530          (----------*-----------)
CN4  -3.756   0.238  4.231      (-----------*----------)
                           -------+---------+---------+---------+--
                                -3.5       0.0       3.5       7.0

CN2 subtracted from:

     Lower  Center  Upper  -------+---------+---------+---------+--
CN3  -4.620  -0.627  3.367     (----------*-----------)
CN4  -5.919  -1.926  2.068  (----------*-----------)
                           -------+---------+---------+---------+--
                                -3.5       0.0       3.5       7.0

CN3 subtracted from:

     Lower  Center  Upper  -------+---------+---------+---------+--
CN4  -5.293  -1.299  2.694   (----------*-----------)
                           -------+---------+---------+---------+--
                                -3.5       0.0       3.5       7.0
```

Results of GI of all compost piles

One-way ANOVA: GI1, GI2, GI3, GI4

```
Source  DF     SS     MS      F      P
Factor   3  30752  10251  67.84  0.000
Error   44   6648    151
Total   47  37399

S = 12.29   R-Sq = 82.22%   R-Sq(adj) = 81.01%

                        Individual 95% CIs For Mean Based on
                        Pooled StDev
Level   N    Mean  StDev  ----+---------+---------+---------+-----
GI1    12  188.71  18.41                          (-*--)
GI2    12  151.80  10.24              (--*--)
GI3    12  133.56   8.68        (-*--)
GI4    12  121.80   9.23  (--*--)
                          ----+---------+---------+---------+-----
                            125       150       175       200

Pooled StDev = 12.29

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons

Individual confidence level = 98.95%

GI1 subtracted from:

      Lower  Center   Upper  ---+---------+---------+---------+------
GI2  -50.32  -36.91  -23.50           (--*---)
GI3  -68.56  -55.14  -41.73       (---*---)
GI4  -80.32  -66.91  -53.49  (---*---)
                             ---+---------+---------+---------+------
                               -70       -35         0        35

GI2 subtracted from:

      Lower  Center   Upper  ---+---------+---------+---------+------
GI3  -31.65  -18.23   -4.82               (---*---)
GI4  -43.41  -30.00  -16.58             (--*---)
                             ---+---------+---------+---------+------
                               -70       -35         0        35

GI3 subtracted from:

      Lower  Center  Upper  ---+---------+---------+---------+------
GI4  -25.18  -11.76   1.65                  (---*--)
                            ---+---------+---------+---------+------
                              -70       -35         0        35
```

BIOGRAPHY

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